

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE &
TECHNOLOGY, UDAIPUR
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated : 16-01-2009

CERTIFICATE - I

This is to certify that **Mr. ANIL MEHTA** has successfully completed the comprehensive examination held on 22nd August, 2007 as required under the regulations for Master of Engineering in Irrigation Water Management Engineering.

(Dr. R.C. Purohit)

Professor & Head

Department of Soil & Water Engineering

College of Technology and Engineering, Udaipur

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE &
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COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated: 16-01-2009

CERTIFICATE - II

This is to certify that research work presented in this thesis entitled **“Ecotechnological Management and Operation of Selected Surface Reservoirs of Upper Berach Basin, Udaipur”** submitted for the degree of Master of Engineering in the subject of **Irrigation Water Management Engineering** embodies bonafide research work carried out by **Mr. Anil Mehta** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on the 5th Dec. 2008.

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(Dr. R.C. Purohit)
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**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE &
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Dated: 11-02-2009

CERTIFICATE - III

This is to certify that this thesis entitled “**Ecotechnological Management and Operation of Selected Surface Reservoirs of Upper Berach Basin, Udaipur**” submitted by **Mr. Anil Mehta** to Maharaja Pratap University of Agriculture & Technology, Udaipur, in partial fulfillment of the requirement for the degree of **Master of Engineering** in Agriculture engineering in the subject of **Irrigation Water Management Engineering**, was after the recommendation by the external examiner and defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on his thesis has been found satisfactory; we therefore, recommend that the thesis be approved.

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Approved
Director Resident Instructions
MPUA&T, Udaipur

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE &
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Dated: 12-02-2009

CERTIFICATE - IV

This is to certify that **Mr. Anil Mehta** student of **Master of Engineering** in agriculture in the subject of **Irrigation Water Management Engineering**, Department of Soil and Water Engineering, has made all corrections / modifications in the thesis entitled **“Ecotechnological Management and Operation of Selected Surface Reservoirs of Upper Berach Basin, Udaipur”** which were suggested by the external examiner and the advisory committee in the oral examination held on 11-02-2009 and the final copies of the thesis duly bound and corrected have been submitted on 12-02-2009.

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The Director Resident Instructions,

MPUAT, Udaipur

Through : Proper channel

Dear Sir,

Kindly find enclosed herewith four copies of bound thesis of Mr. Anil Mehta M.E. (IWME), student, Department of Soil and Water Engineering, CTAE for your kind approval.

You are requested to kindly sign and return the same. As desired he has already submitted the research paper at the time of evaluation of the thesis.

Thanking you,

Your's Faithfully

HEAD, SWE

Enclosed :

1. Four copies of bound theiss with CD.
2. Viva-voce report.
3. Bio-data performa.
4. Certificate 1 to 4 & cover page.

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CTAE, Udaipur

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE &
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Viva-Voce Report

Date : 11-02-2009

This is to certify that the thesis entitled “**Ecotechnological Management and Operation of Selected Surface Reservoirs of Upper Berach Basin, Udaipur**” submitted by **Mr. Anil Mehta** to the MPUA&T, Udaipur, in partial fulfillment for the Degree of **Master of Engineering** in Agriculture in the subject of **Irrigation Water Management Engineering** and recommended by the external examiner was examined orally by the committee consisting of undersigned. The committee recommends that :

- (1) The performance of the candidate has been found satisfactory. We recommend the acceptance of the thesis for the award of degree.
- (2) The performance of the candidate has been found unsatisfactory. The candidate be asked to re-appear in the oral examination.

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Forwarded by the Head, Department of Soil and Water Engineering to :-

1. The Director Resident Instructions, MPUA&T, Udaipur with three copies of bound thesis.
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College of Technology and Engineering

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Udaipur-313001

No. CTAE/SWE/2008-09/

Dated : 12-02-2009

CERTIFICATE

This is to certify that research work presented in this thesis entitled “**Ecotechnological Management and Operation of Selected Surface Reservoirs of Upper Berach Basin, Udaipur**” submitted by **Mr. Anil Mehta** in the subject of Agricultural Engineering (**Irrigation Water Management Engineering**) to Maharana Pratap University of Agricultural and Technology, Udaipur in partial fulfillment of the requirement for the award of the degree of M.E./Ph.D. had been carried out under the guidance and supervision of every member of the advisory committee and the manuscript of the thesis was also critically checked and necessary corrections were incorporated.

Chairman and Major Advisor

**INFORMATION REQUIRED BY THE OFFICE OF THE D.R.I., MPUA&T,
UDAIPUR FOR APPROVAL OF BOUND MASTERS/PH.D THESIS**

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Title of Thesis	English	: Ecotechnological Management and Operation of Selected Surface Reservoirs of Upper Berach Basin, Udaipur
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Secured by the student		
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ABSTRACT

The Upper Berach Basin (Udaipur Valley)is a fifth order drainage system of river Ganga and is dotted with numerous big & small surface water reservoirs, important being Pichhola, Fateh Sagar, Badi, Madar & Udai Sagar. These reservoirs are the lifeline of Udaipur, the Lake City of Southern Rajasthan, India.

These reservoirs play an important role in hydrological and ecological balance of Upper Berach Basin. They provide water for drinking, irrigation, industries & recreation. They are simultaneously instrumental in recharging of ground water, flood control, maintenance of micro climate and mitigation of drought.

The non resilient, vulnerable reservoir eco systems are facing serious environmental problems like change in runoff patterns, frequent drying, contamination of impounded water by solid and liquid wastes excessive withdrawal and deterioration of overall ecological health.

Though these reservoirs are the lifeline of Udaipur & survival of it's citizens, but no operation and management plan based on eco technological approach has been developed so far by any agency. To be effective in eco technological sense, it is necessary that eco techniques based on mathematical optimization should be developed & implemented to ensure efficient, effective & ecologically sound utilization of these reservoirs.

Deterministic models using linear programming are developed using 38 years hydrological data of upper Berach basin to develop decision rules for operation & management of selected surface reservoirs in this Basin. These decision rules will not only fulfill various demands but at the same time maintain, conserve & sustain the eco system health of the important reservoirs of upper Berach basin, Udaipur.

Key words - Ecosystem, Ecotechnological Management, Reservoir Operation, Optimization, Linear Programming, Decision Rule.

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1. INTRODUCTION

1.1. General

United nations organization has declared the decade 2005-2015 as 'International Decade for Action - 'Water for Life'. Fresh Water, essential for life, makes up only 0.01percent of the world water and approximately 0.8 percent of the earth surface. Yet this tiny fraction supports 6 percent of the all described species (Anonymous, 2005, a). Inland water constitutes valuable natural resource in ecological, economic, social, cultural, aesthetic, scientific and educational terms. Their action based conservation and management are critical to the interest, survival and sustenance of mankind.

Reservoirs, which contain 90 percent of the fresh water and 14 percent of the global annual runoff, play an important role in hydrological and ecological cycle. Reservoirs are important for human development and for the preservation of sound ecosystems and biodiversity. The earth is dotted with millions of reservoirs filled with water, including natural depressions called lakes.

It has always been the attempt of human beings to bring water into their vicinity, ever since the beginning of civilization itself. This led to the creation of man made lakes. Reservoirs are most often built in regions that lack a substantial number of lakes due to geologic and climatic constraints. In water-scarce arid and semi arid regions of Rajasthan, thousands of manmade lakes were created during the medieval times by the then erstwhile rulers.

Reservoirs are impoundment of water against an embankment. It is a basin constructed in the valley of a river or stream for the purpose of holding stream flow so that stored water may be used to meet various demands associated with it. Reservoirs provide multi purpose uses of different values to humans. They supply water for drinking, agriculture, industry, live stock uses and energy generation. They play an essential role in ground - water recharge, flood control and drought mitigation.

As time passes after construction, reservoirs shift themselves to lake and wetland environments. They do not remain just water holding tanks, a gradual transition to 'ecosystem' takes place and they thus become critical element of water and ecological cycle. A lake is an ecosystem, a community of interaction among animals, plants, microorganisms, and the physical and chemical environment in which they live.

Reservoir ecosystems are non resilient and vulnerable when faced with well known environmental problems like waste discharge, catchment deterioration, erratic rainfall, change in runoff patterns, introduction of exotic species, arid and semi arid climate, transport of airborne and water borne nutrients and contaminants. These problems can normally be

grouped into three major categories : water quality, quantity, and ecosystem problems. Increasing populations impose increasing demands for water supplies, often leading to unsustainable withdrawals. Activities of humans, industry, and agriculture generate wastes that are usually discharged into water bodies. Finally the environment and supporting ecosystems require water, and meeting those requirements often conflicts with meeting other demands.

The "World Lake Vision" (Anonymous, 2003) warns that excessive water withdrawal from reservoirs seriously threatens the biological community they support and alter the shore line characteristics. Therefore, adequate level of water is essential for human survival and, most importantly, for maintaining and sustaining the life supporting reservoir's ecosystem. The eleventh five year plan (2007-2012) report also underlines the importance of water for nature. The report says that the question of trade off between competing claims on water resources has become the most important in the context of ecological requirements. The report describes that the National Water Policy places ecology in the fourth place in the order of priority for water use; Yet there is general agreement among all that any water diversion need to take care of river ecosystem.

The World Lake Vision emphasize the need of proper water budgeting to manage water withdrawals from reservoirs so as to meet various demands including the quantity of water needed to preserve ecosystem functions. The International Decade for Action - Water for Life invites attention and interventions of scientist's community, and imposes responsibilities on water technologists and managers to draw a suitable action plan to maintain a conservation pool level in the reservoirs. This can be done only by eco-technological management and operation of reservoirs.

1.2. Importance & Need of the Study

The world population is predicted to grow from six billion at present, to about nine billion by the year 2050. India and China will share almost 33 percent of the total population. The population of our country is estimated to grow from 1.2 billion to 1.62 billion.

The growing population is exerting great pressure on water reservoirs and excessive, unplanned, wasteful withdrawal is resulting in irreparable effect on life and sustenance of reservoirs. On the other hand, the climatic and topographical changes have adversely affected the inflow to the reservoirs. The "Intergovernmental Panel on Climate Change" (IPCC Report 2001) has predicted that for the western region of India, there will be changes in annual run off from 50 to 150 mm per year. Further, the ever rising population is exerting great pressure on water resources. The world population is predicted to grow from present 7113 million to 7877 million by the year 2025; this will alter the entire water

dynamics because of rise in agricultural, municipal and industrial water demands (Table 1). This will result in excessive withdrawal of water. The reduced inflows and overexploitation of water without any considerations for ecological needs of reservoirs are accelerating the death process of these fragile, sensitive ecosystems.

Table 1: Dynamics of world water use (Km³ /year)

Sector/Year	1960	1995	2010	2025
Population (Million)	3029	5735	7113	7877
Agricultural Use	1481	2504	2817	3189
Municipal Use	118	344	472	607
Industrial Use	339	752	908	11170

(Shiklowmanov, 2000)

An optimal conservation level of water in reservoirs is essential for human survival and socioeconomic development, but primarily and most importantly it is essential for sustenance of life supporting, socio-economically important reservoir ecosystems. To achieve this goal, the ecological water needs of the reservoirs should be given the equally important priority in water allocation, and accordingly optimization models should be drawn.

1.3. Justification

Eco-technology has been defined as the use of technological means for ecosystem management, based on deep understanding of principles on which natural ecosystems are built; and on the transfer of such principles into ecosystem management in a way so as to minimize the cost of measures and their harm to environment, and to derive optimum benefits. Optimal planning is necessary to apply aforesaid technological principles. This optimal planning can be defined as the process which develops an agreed set of goals and means for achieving those goals, typically within a particular time frame and resource constraints. Therefore, it is necessary that the technologists and the managers of lake basin reservoirs should prevent potential problems, overcome existing problems, and maximize the various benefits through eco-technological structural and non structural measures. To be effective in the eco technological sense, the eco-techniques have to be used with the help of mathematical optimization models. Such models will ensure effective efficient and ecologically sound utilization of limited water reservoirs.

1.3.1. Basin Approach

The world's freshwater supplies are located within basins and aquifers . There are some 260 international river basins, covering a little less than a half of the land surface of the globe and affecting about 40 percent of the world's population (Anonymous 2005). India has 13 major river basins and most of them are water stressed. (Plate 1)

Integrated Water Resource Management (IWRM) is becoming increasingly accepted as the appropriate frame-work for managing water resources in river basins, because IWRM takes account of the interrelation and integrating nature of the reservoirs that lie within the basin. (Anonymous, 2004, a).

Reservoirs and their drainage basin form an inseparable system. To derive optimum benefit, it is therefore necessary to simultaneously plan, manage and operate the system of reservoirs in a particular basin.

The upper Berach basin (Udaipur), which is a fifth order drainage system of river Ganga, is dotted with numerous big and small reservoirs. These reservoirs are life line of the Udaipur valley. The reduced inflows and over exploitation of reservoir waters have threatened the entire social, economical and ecological sustenance of the upper Berach basin. Therefore, there is an urgent need to draw practical action plans for eco technological conservation of these reservoirs of semi- arid region of southern Rajasthan. The approach for the same should be based on lake basin management, so as to use and operate them equitably, efficiently and in a sustainable way.

1.4. Objectives of the study

The study on ecotechnological management and operation of selected surface reservoirs of upper Berach basin, Udaipur is undertaken with the following objectives

1. To delineate inter-linked surface reservoirs of upper Berach basin.
2. To make an assessment of reservoir's water storage and utilization.
3. To develop an optimal operation plan and to frame recommendations for eco technological management of selected surface reservoirs

Plate - 1

2. REVIEW OF LITERATURE

The relevant literature about eco-technological management and operation of surface water reservoirs has been collected, studied and reviewed. The various earlier researches related to upper Berach basin were compiled to understand the hydrological, environmental and ecological processes. The literature has been reviewed under the following heads:

- **Hydrology, Rainfall - Analysis and Estimation of Runoff**
- **Evaporation from Reservoirs**
- **Seepage Losses from Reservoirs**
- **Sedimentation in Reservoirs**
- **Eutrophication**
- **Reservoir Operations and Eco Technological Management**

2.1. Hydrology, Rainfall-Analysis and Estimation of runoff

Kumar (1995) analyzed the daily rainfall data of 28 years recorded at Pantnagar to calculate 5 days antecedent rainfall preceding the storm. The observed values of 5 days antecedent rainfall calculated by Weibul's formula and expected values computed by different distributions were compared at 1.25, 5, 10, 100 and 1000 years recurring intervals. It was found that all the distributions i.e. Normal, Log Normal, Pearson type I and Log Pearson type III fit well to the observed data. The average percentage deviation of computed values from observed one was found to be minimum for Pearson type I distribution and therefore, it was used to calculate the 5 days antecedent rainfall required for the estimation of runoff using curve number method.

Rana and Thakur (1995) studied the annual, seasonal, monthly and weekly data of Kullu valley in Himachal Pradesh to obtain the rainfall distribution pattern using three different theoretical frequency distributions e.g., Pearson type III, Log Normal and Gumbel. They found that the data of 19 years was sufficient to obtain weekly, monthly, seasonal and annual rainfall distribution pattern of the area. They also reported that Gumbel distribution fit best to observed rainfall data. The expected and observed frequencies were found to be in good agreement with each other.

Subudhi *et al.* (1996) analyzed the 28 years rainfall data at Phulbani and observed that 76 percent of the annual rainfall was received from July to October. Frequency analysis for maximum annual rainfall data was done by using Weibul's technique. They estimated the monthly, seasonal and annual rainfall at 70 percent probability level and found that Kharif season received 839 mm rainfall and suggested the crop varieties with growing period of four months.

Rao *et al.* (1998) planned inter seasonal water requirements for the reservoir based project at Jayakwadi Irrigation Project, Maharashtra. For this daily runoff values were estimated from the data of daily rainfall using the SCS curve number method (USDA, 1972) adopted for Indian conditions. The runoff equation for the black soil condition in India was used.

Pawar (2001) estimated surface runoff for Ahar river catchment and Udai Sagar catchment by using SCS curve number method. It was observed that surface runoff contribution from Ahar river catchment was more than that from Udai Sagar catchment. He also concluded that annual surface runoff from the catchment is not dependent only on total amount of rainfall but it also depends on the amount of daily rainfall events and rainfall distribution.

Guerra *et al.* (2003) quantified the major hydrological parameters of four selected farm reservoirs using a water balance approach. Direct rainfall and runoff from the catchment area contributed, respectively, about 36 percent and 64 percent to reservoir inflow. Typically, farmer's use of stored water for land preparation and irrigation of rice accounted for about 30 percent of the total water outflow from a reservoir. Seepage and percolation losses of water accounted for about 45 percent of the outflow volume, and evaporation losses of about 25 percent. The minimum catchment area required to support a reservoir of given capacity was calculated to be nearly five times higher for a grassed catchment than for a catchment under paddy rice. The hydraulic conductivity of reservoir embankments reduces with reservoir age due to continuous settlement of poorly compacted materials, affecting the water loss through seepage.

Anonymous (2005, a) found that the primary reason for in significant amount of water received at Pichhola and Fateh Sagar is the inadequate and scanty rainfall in the catchment areas. The intensity and quantum of rainfall were insufficient to create adequate run off for substantial amount of water to reach the lake beds. This point was further strengthened by the studies conducted at Rajasthan State Mines & Minerals Ltd. (RSMML)

with respect to rainfall data of year 2005 and the rainfall received in the year 1994, 1998, and 2002. The analysis established the inter-relationship of intense short period rainfall and creation of adequate flow of water on channels. Another study conducted by District Collector, Udaipur using day to day data for the month of August for 10 years, amply proved that over the years, heavy rainfall received within a duration of a couple of weeks triggered off healthy runoff and lakes did swell almost suddenly under such circumstances. The peculiar geography and rock type of the catchment determine the crucial factor of the saturation of the carrying system for maximizing the run off. In the year 2005, the rainfall received being 50 percent of average/normal rainfall and further distributed over a prolonged duration is the principal factor for not generating any significant water flow to the lakes. Data showed that the maximum rainfall received in a day in the crucial month of August 2004 never exceeded 33 mm. The data also indicated that such situation was not unprecedented. In the past, Fateh Sagar water-level has fluctuated widely, specially in the years 1962, 1966, 1969, 1972, 1974, 1982, 1987, 2002. In the period 1987-91 yield and quantity variations of Pichhola lake has shown wide fluctuations. The data depicting departure from mean annual rainfall for the period 1921-1990 also shows at least 29 prominent deficient years. As on 31st August, 2004, the reservoirs at Madar and Nandeshwar contained less than 1/3rd of their capacity indicating thereby that the hills of Gogunda and Alsigarh did not receive adequate rainfall in the year 2004.

Khobragade (2005) pointed out that each lake has its own set of problems depending upon its morphology, climate of the catchment, land use in the catchment, degree of human interference in the catchment and use of lake water along with other environmental factors. The lakes particularly in arid and semi-arid regions may face the problems of heavy evaporation and reduced inflows and may even dry out completely in summer as in the case of some lakes in Rajasthan. Restoration of any ecosystem refers to any active attempt to return the ecosystem to an earlier condition following degradation resulting from any kind of disturbance.

Khobragade *et al.* (2005) analyzed the rainfall data for two stations (CTAE Meteorological Lab and Irrigation Observatory) in Udaipur. The trend analysis was carried out using statistical tests such as Kendal's Rank Correlation Test, Spearman-Rho Test and Linear regression test. No significant decreasing trends were detected in these tests, although a decline in the trend did appear in the plot, due to exceptionally high rainfall of 1973. The author found that if the data are split in three decades (1973-1982), (1983-1992) and (1993-2002) then the average values of the three decades show a declining trend. The rainfall in the year 2003 (and even in the year 2004) was more than the normal rainfall or the average

rainfall over the last three decades, yet a decline in the inflow to the lake was observed. Apparently it appears that the declining levels in the lake are not due to decreasing rainfall. However, since the rainfall data does not pertain to the catchment, and the variation of rainfall is not known, it would be erroneous to arrive at definite conclusions regarding the relationships between the rainfall and the lake water levels. The authors indicated that this is because the water levels in the lake are also affected by evaporation rates, sub-surface outflows from the lake and withdrawal of water from the lake through pumping etc. The author suggests that a detailed analysis on the long term data (of a century or so, which is known to be available for Udaipur) needs to be carried out along with the characteristics of precipitation such as intensity, duration, number of storms etc.; but the discussion with the local people indicates that precipitation regime of the area has changed over the years. Unlike the past, less intense rains of shorter duration are being received, and they are unable to produce the required runoff. The researchers pointed out that limnological studies alone are inadequate for an overall understanding of the hydrological behaviour of the lake ecosystem as they do not consider the various hydrological aspects. It was pointed out that no inflows data are available for the lake as the inflow is not being monitored, and also, there is no controlled outflow from the lake. The overflow, if any, is not being measured. Authors used lake water balance approach to analyze the inflow regime. The major outflow is the evaporation losses, withdrawal from the lake and possible sub-surface outflows (seepage losses). The Data for seepage analysis were not available. Therefore, for the preliminary assessment on an annual basis, the term net ground water flow (ground water inflow-ground water outflow) was assumed as negligible. There are two pumping stations for Lake Pichhola. The data of only Dudh Talai station was used by the authors, and a reasonable assumption for the other station was made after discussion with the authorities of PHED Department. Monthly average data for withdrawal was collected from PHED for the period 1990-2003 and using these values annual losses due to withdrawal were calculated. Data on pan evaporation were obtained from the CTAE, Udaipur. Lake evaporation has been estimated from the pan data by applying a coefficient of 0.7 which is reasonable assumption only for annual basis. Maximum and minimum water level data were obtained from the Irrigation Department, Udaipur along with the depth area capacity curve. Using these data, change in annual storage was estimated. For estimating volume of water lost through evaporation, the water spread area of the lake was calculated as average of the water spread area at maximum and minimum water levels. The inflow from the catchment was calculated as total inflow minus direct precipitation over the lake. After detailed analysis authors concluded that the inflow has reduced considerably over the last few years. The inflow to the lake was about 17.5 mcm in 1991 and about 19.5 in the year 1993. It came down to about 16

mcm in the year 1997 and 1998, and further reduced to about 4.4 cubic m in the year 2001 to 2002.

Rathore (2005) observed that Udaipur Basin has been receiving inadequate rainfall for the past five years continuously due to which the lakes were not replenished. Udaipur Basin is a transitional zone between sub humid region in the south and semi-arid region in the north. 50 cm isohyets lie along the north west of Udaipur and separate it from the arid west. Due to this, uncertainty and erratic nature of rainfall always prevails.

Kebede *et al.* (2006) determined the annual water budget of Lake Tana from estimates of runoff, rainfall on the lake, measured outflow and empirically determined evaporation. Simulation of lake level variation (1960–1992) has been conducted through modeling at a monthly time step. Despite the ± 20 percent (%) rainfall variations in the Blue Nile basin in the last 50 years, the lake level remained regular. A preliminary analysis of the sensitivity of level and outflow of the lake suggests that they are controlled more by variation in rainfall, than by basin-scale forcing induced by human activities. The analysis shows that a drastic (40–45 percent) and sustained (7–8 years) rainfall reduction is required to change the lake from out flowing to terminal (cessation of outflow). However, the outflow from the lake shows significant variation responding to the rainfall variations. Unlike the terminal lakes in the Ethiopian Rift Valley, or the other large lakes of Tropical Africa, in their present hydrologic conditions, the Lake Tana level is less sensitive to rainfall variation and changes in catchment characteristics.

Kumar (2007) used Soil Conservation Services (SCS) Curve Number method to determine runoff for Badi, Madar, Pichhola, Fateh Sagar reservoirs of upper Berach basin, Udaipur. The weighted curve number of the Badi watershed for Antecedent Moisture Condition II (AMC) was worked out to be 83.5. The corresponding curve numbers for AMC I and AMC III were 67 and 93 respectively. The weighted curve number of the Chhota Madar watershed for normal condition was found to be 83.5 and the corresponding curve number values for AMC I and AMC III conditions were worked out to be 67 and 93 respectively. The annual runoff for Badi and Chhota Madar watershed varied from 2.08 (0.71 percent) mm in year 1987 to 326.20 mm (37.32 percent) in 2005. The weighted curve number of the Bada Madar watershed for AMC II was calculated as 82. The corresponding curve number values for AMC I and AMC III were worked out to be 66 and 91.5 respectively. The mean annual runoff of the watershed for thirty years was found to be 13.89 percent. The lowest runoff obtained were 1.14 percent, in the year 1987 whereas the highest runoff obtained was 31.10 percent in the year 2005. The weighed curve number of the Fateh Sagar watershed for AMC II was found to be 83. The corresponding curve number values for AMC I and AMC III were

calculated to be 76 and 92 respectively. The annual runoff of Fateh Sagar watershed calculated by SCS curve number method was obtained by summing up the daily runoff of the year. Out of these thirty years, the runoff up to 10 percent was observed in 11 years, 10 to 20 percent in nine years and 20 to 36 percent in the remaining 10 years. The weighted curve number of the Pichhola watershed for AMC II was found to be 79. The corresponding curve number values for AMC I and AMC III were found to be 62 and 91 respectively. The hydrologic condition of the watershed was found fair to good due to soil and water conservation measures implemented in some parts of the watershed. In the year 1987, the runoff from watershed was 0.19 mm which is nearly zero whereas maximum runoff of 301.93 mm (34.54 percent) was observed in 2005. The mean annual runoff of thirty years was found to be 12.18 percent.

Tiwari *et al.* (2007) developed a methodology to characterize meteorological drought for drought prone area of Hazirabagh district of Jharkhand. The annual and monsoon seasonal rainfall data for a period of 80 years were analyzed to determine excess and deficit from normal. Rainfall is a major contributor of precipitation in Indian tropical region and the spatial and temporal uneven distribution of rainfall leads to occurrence of flood and drought in different regions simultaneously. In India, the natural hazards, such as drought, adversely affect the water availability for domestic, agricultural and industrial uses and create havoc; and people resort to nomadic life styles to cope with the shortage of water. Drought is one of the several natural calamities, which build up slowly; unlike flood, no systematic methods have yet been developed either for their complete understanding or for their prediction. The authors referred various drought classification approaches in their study : India Meteorological Department (IMD, 1971) classified the drought years as per percentage rainfall deficiency. IMD classified the drought years into slight, moderate and severe drought as per percentage rainfall deficiency of 11 percent to 25 percent, 25 percent to 50 percent and more than 50 percent respectively. Palmer (1965) developed a drought severity index as a function of accumulated weighted difference of the actual precipitation and precipitation requirements. He classified drought severity according to the index; as incipient from 0.5 to 0.99 indexes, as mild from 1.0 to 1.99, as moderate from 2.0 to 2.99, as severe from 3.0 to 3.99, and 4.0 for extreme drought. Subrahmanyam and Subramaniam (1964) used the population mean μ and the standard deviation σ of the annual rainfall to classify the drought years, the years with rainfall between μ and $\mu - 1/2 \sigma$, $\mu - 1/2 \sigma$ and $\mu - \sigma$, $\mu - \sigma$ and $\mu - 2 \sigma$ and lesser than $\mu - 2 \sigma$ are termed as moderate, large, severe and disastrous drought years respectively. Kanitkar *et al.* (1960) classified a year as drought and famine if the rainfall deficiency from the normal annual rainfall is more than 20 percent and 33 percent respectively. Linsley *et al.* (1959) define droughts as "a sustained period of time without

significant rainfall". Thornthwaite (1948) classified three types of drought : (1) the permanent droughts of the driest climates, like in arid regions, (2) the seasonal droughts in climates having well defined wet and dry seasons generally in tropical areas, and (3) the contingent droughts resulting from irregular and variable occurrence of rainfall in areas with normally sufficient rainfall. The type of drought varies from place to place, depending upon the climate of the place. India is a vast country, and it experiences all three types of droughts in its different parts. Tanehill (1947) defined drought as a phenomenon that is popularly known as 'spells of weather'. According to water balance concept, drought is a physical condition of the environment in which the amount of water available from precipitation and soil reservoir is insufficient to meet the evapo-transpiration demand of crops; while for a meteorologist drought means a deviation from normal precipitation. Walker (1912) classified the drought as large, serious, and disastrous for the rainfall deficiency of 30 percent and 45 percent, 45 percent and 60 percent, and above 60 percent of the normal annual rainfall respectively.

2.2. Evaporation from Reservoirs

Linacre (1994) pointed out that it is hard to measure the rate of evaporation (E_0) from a lake. It is best estimated from Penman's formula, or a derivative of it, if only few input data are available. However, a common alternative is to measure the evaporation from a pan, such as a U.S. Class-A pan and then multiply the measurement E_p by a factor. E_p is easily measured as the rate of fall of the level of water exposed in a pan, minus any rainfall. The factor (the ratio E_p / E_0 , usually called the 'pan coefficient') is often taken as about 1.3.

That implies that there is 30 percent more evaporation from the small area of a pan than from a lake because of the extra heat taken in through the pan's sides. However, a comparison of Penman estimates of E_0 with measured E_p shows that the factor is not a constant but depends on the rate of evaporation. Values of the factor are indeed scattered about 1.3 if E_p is less than approximately 5 mm/day, but they are more at higher rates, e.g. around 1.7 when E_p is 12 mm/day. In other words, the extra heat through the walls of the pan increases disproportionately; in high-evaporation conditions.

Chiew and McMahon (1996) discussed that estimates of potential evapotranspiration are required to serve as an aid for estimating actual evapotranspiration. Penman's combination equation is generally accepted as an appropriate method for estimating potential evapotranspiration. However, as all the climatic data required to calculate Penman's potential evapotranspiration are seldom available. Potential evapotranspiration is more commonly approximated as a factor time's standard evaporation pan reading. In this paper, linear regression equations relating Penman's potential evapotranspiration for land surfaces to Class

A evaporation pan data over several time periods are developed for various climatic regions throughout Australia. The analysis indicated poor correlations between daily estimates of Penman's potential evapotranspiration and pan data, and therefore, pan data be treated with caution if used to approximate daily potential evapotranspiration. The correlations improve over longer time periods, and the equations developed for three-day and weekly totals may be used as a last resort to approximate potential evapotranspiration in areas where climatic data required to calculate potential evapotranspiration are not available.

Sur *et al.* (1999) showed that 73 percent, 77 percent, and 85 percent of the total summer monsoon rains could produce runoff with runoff coefficients of 0.22 ± 0.33 , 0.37 ± 0.04 and 0.35 ± 0.05 , at the respective sites. On an average 1211, 2712, 2769 m³ of water was harvested per hectare in the structures. From the harvested water 79 percent, 78 percent and 46 percent was lost through evaporation and seepage. The major mode of the water loss was seepage which varies from 61 percent to 86 percent at these sites. The water harvesting structures lost their gross storage capacity by 1.30 percent, 1.08 percent and 1.16 percent per year with siltation rate of 31, 37 and 47 ton per hectare of catchment area at Ballawal Sounkhri, Takarla and Karoran, respectively. The ratio of command to catchment area, for providing single irrigation was 0.51, 1.4 and 2.9 at the respective sites.

McKenzie and Craig (2001) pointed out that accurate estimates of evaporation losses are important to manage the river's resources efficiently. The authors studied releases (into the Orange River from Vanderklo Dam) that flow some 1400 km through extremely hot and arid areas. This study was initiated to improve estimates of river losses downstream of Vanderklo of Dam, and to develop a methodology for estimating evaporation losses from South African rivers. Theoretical losses were estimated from a measured evaporation rate multiplied by the water surface area and an appropriate riparian vegetation area. In addition, hydraulic modeling was used to perform a dynamic water balance to verify the initial loss estimate. Evaporation rates from a flowing river (in an arid region) were found to be in the same order of magnitude as pan evaporation data. The evaporation losses from the Orange River derived from this research range from 575 million m³/a at an annual low flow release rate of 50 m³/s to 989 million m³/a at an annual release rate of 400 m³/s. The variation in evaporation losses is due to the change in surface area with flow.

Christine *et al.* (2001) estimated evaporation from an open shallow lake in tropical Africa (Lake Ziway, Main Ethiopian Rift) made by using monthly hydro meteorological data available for the past three decades. On the one hand, annual average estimates are inferred from three climatic approaches, which can be applied in areas with limited meteorological data. The lake energy balance yields an evaporation rate of 1780 mm yr⁻¹, assuming a Bowen

ratio of 0.15 (that of Lake Victoria). The Penman method gives an annual evaporation rate of 1870 mm. The complementary relationship lake evaporation model (CRLE) applied on monthly averaged values of air temperature, air humidity and sunshine duration gives 1730 mm yr⁻¹. The sensitivity of each method to changes in input variables is analyzed in order to test the stability of the resulting estimates. This helps discuss uncertainties and possible inter-annual variations of the evaporation rate. On the other hand, the monthly lake level records together with precipitation and river discharge data between 1969 and 1990, allow us to estimate the water balance, providing an annual rate of 1937 mm for the combined evaporation and groundwater losses. The chloride budget is used to discriminate the groundwater from the evaporation loss. It gives us an annual evaporation rate of 1740 mm and a corresponding groundwater loss of 200 mm yr⁻¹.

Jensen (2005) estimated lake evaporation using 17 month data for Lake Berryessa. The climatic and Lake Berryessa (LB) temperature profile data collected from May 2003 to September 2004, estimates lake evaporation using the Penman-Monteith equation. Current evaporation estimates by the U.S. Bureau of Reclamation (USBR) are based on Class A pan evaporation and the original pan coefficients developed in the 1960s. The location of the pan is not fixed & it has been changed several times. Further measured pan evaporation measured at the current or old site is much lower than that measured at a new site that is fully exposed to solar radiation. Estimates of P-M evaporation were reduced by a factor of 0.95 because a small part of the lake surface area is partially under shade for some time of the day, and also because the data were measured at a location beyond the basin of the lake. He observed that the P-M evaporation estimates and estimates using pan evaporation at the new site with Lake Elsinore monthly pan coefficients indicated that USBR evaporation estimates are about 20 percent too low mainly because of pan site conditions. A computer model was also developed to process, store, and calculate estimated daily or monthly evaporation from the lake.

Khobragade *et al.* (2005) described that evaporation rates are generally high for lakes in arid and semi arid regions which is true for lake Pichhola of Udaipur also. They conducted water balance of the reservoir from 1991 to 2002 and derived that evaporation losses from the lake showed increasing trend over the years. As per water balance estimates the overall losses are almost 50 percent of the river inflow to the lake and is about 30 percent of the total inflow to the lake (river inflow+ direct precipitation over the lake). Although evaporation is a natural process, the presence of macrophytes such as water hyacinth is known to cause heavy transpiration losses. The study indicated the shallow depth of the lakes as another important factor. Since evaporation is caused by a surface energy transfer, the more the exposed area, more is the loss of water by way of lake evaporation, i.e. for the same

volume of water stored in the lake if the surface area is reduced by increasing the depth of the lake.

Stephen *et al.* (2005) estimated significant water losses through seepage and evaporation, which accounts on average for 30-50 percent of the stored runoff, is one of factors that affect the adoption and up-scaling of on farm water storage systems.

Zhang *et al.* (2008) are studying various different approaches for estimating evaporation over an open water surface; and pointed out that evaporation is an important component of hydrological cycle. Estimating evaporation using conventional meteorological data is still a very useful approach for studying long-term evaporation trends given the large amount of available datasets. However, improving the accuracy of the approaches, which use conventional meteorological data to estimate evaporation, is still challenging due to their applicability in different surfaces and different locations. In this study, authors are evaluating eight approaches(viz. Haise, Penman, Mass transfer, DeBruin-Keijman, Priestley-Taylor, Hamon, DeBruin, and Brutsaert-Stricker) , which are frequently used for evaporation estimation. The research site is located in the Rose Barnett Reservoir, Mississippi, and U.S.A. The total area of the reservoir is about 33,000 acre

2. 3. Seepage Losses from Reservoirs

Richard and Peter (2002) presented a review of methods that are based on groundwater-level data. The water-table fluctuation method may be the most widely used technique for estimating recharge; it requires knowledge of specific yield and changes in water levels over time. Advantages of this approach include its simplicity and insensitivity to the mechanism by which water moves through the unsaturated zone. Uncertainty in estimates generated by this method relate to the limited accuracy with which specific yield can be determined and to the extent to which assumptions inherent in the method are valid. Other methods that use water levels (mostly based on the Darcy equation) are also described. The theory underlying the methods is explained. Examples from the literature are used to illustrate applications of the different methods.

Someshwar *et al.* (2005) performed isotopic investigations of ground water component in the lake Pichhola, Udaipur. The stable isotope of oxygen analysis for one time sampling was used in investigating the sub surface inflow and outflow components to the Lake Pichhola in the city of Udaipur, Rajasthan. They found that the lake ecosystem that once used to support a wide variety of Fauna is now unable to meet the water demand. The lake is suffering from regular drying. The comparison of water filled area as seen from the toposheet

surveyed in 1964 with that of the remote sensing imagery of year 2000 shows a significant shrinkage of the lake surface area. A long term decline in the lake level/shoreline indicates that the inflows are not balanced with the out flows. Over the past one decade, the lake water level has been reducing continuously, alarming the growing scarcity of water resources in the region.

The continuous abstraction of ground water in the peripheral area of the lake lowers the local water table. This in turn develops a hydraulic gradient and mobilizes the water into the aquifers from the sites where lake is interconnected with the ground water. The extension, of the lake influenced groundwater recharge area can be large enough and can be a significant component in the total inflow from the lake. Therefore, lake planning should include mapping of the effective catchment area in the upper reaches of the lake where any construction can change the inflow to the lake and demarcation of the zone on the surrounding area and the lower reaches of the lake within which groundwater is recharged through lake. Groundwater recharged in the catchment area from foothill to the lake contributes as a base flow component to the lake. Of the total input to the lake storage, precipitation is the dominant component and the base flow is a minor contribution to it. The lake water is largely drawn out from surface and sub-surface abstraction. The sub-surface abstraction is due to groundwater lake water inter action and that is being tapped by the surrounding localities for their regular needs. The southern portion of the lake appears to be more dynamic with respect to the groundwater exchange compared to that in the north. One of the factors causing drying of the lake is the groundwater draft linked with the recharge by the lake. This component can be reduced by mapping areas where groundwater is not directly recharged by the lake. Such areas if tapped for the local water supply can help in reducing the sub-surface losses.

2.4. Sedimentation of Reservoirs

Purohit *et al.* (1991) studied the lake sedimentation and reported the remaining age of Pichhola and Fateh Sagar as 57 and 82 years respectively. The capacities of Pichhola and Fateh Sagar were decreasing at the rate of 23.98 ha.m per year and 14.75 ha.m per year, during the study span (1973 to 1978). The decreasing rate for submergence areas were observed 0.2961 Sq.Km. and 0.171 Sq.Km. per year respectively for these two reservoirs because of sediments deposition in the lake's bed. Pattern of sediment deposition indicated that for Pichhola 31.31 percent of the total sedimentation was dead storage while 68.69 percent sedimentation was in live storage. For Fateh Sagar, these values were 78.72 percent

and 21.28 percent for dead and live storage respectively. The study indicates that water storage capacity above crest level in Pichhola is decreasing faster than that of Fateh Sagar.

Athavale (2003) discussed that rate of silt deposit formation is a key factor in deciding the life expectancy of a dam. Treatment of the catchment area, comprising afforestation and construction of silt traps would reduce the rate of siltation. Construction of surface water harvesting structures (SWHS) in the thousands of watersheds, constituting the catchment area of an existing or proposed large dam, will indirectly produce this benefit of reducing the siltation rate. A SWHS functions as a silt trap, which can be easily scrapped annually, during the summer, when it becomes dry. SWHS also increase the moisture content of local soil and encourage the natural growth of vegetation. This is in addition to providing water for drinking and irrigation to the local population. The SWHS in the catchment area thus have a complementary role in reducing the silt load carried by the main stream and increasing the lifespan of a large dam.

Hankanson *et al.* (2004) presented a model of sedimentation and suspended particulate matter in coastal areas. This paper describes a new dynamic mass-balance model for suspended particulate matter (SPM) and sedimentation in coastal areas handling all important fluxes of SPM to, from and within coastal areas; as such areas can be defined according to the topographical bottleneck method. The model is based on ordinary differential equations and the calculation time is one month to reflect seasonal variations. The model has been validated with good results (the predictions of sedimentation are within the 95 percent confidence limits of the empirical data used to validate the model) against data collected by sediment traps placed in 17 Baltic coastal areas of different character. The model is general and has also been used with similar success for other types of aquatic systems (mainly lakes).

Khobragade (2005) described that sedimentation rate of the lake Pichhola, Udaipur was studied by isotope technique using Pb-210 in the year 2004. The analysis was carried by Nuclear Hydrology Laboratory of NIH using alpha spectrometer and useful life of the lake was estimated. A total number of 177 Sediment samples were collected from 14 cores from different locations in the lake as well as the catchment; by cutting slices of 2 cm thickness. During the period of investigation the mean depth of the lake was only 0.782 m. The estimated sedimentation rate of the lake was 0.48 cm/year. However, it should be noted that these are past rates of sediment deposition and with decline in runoff from the catchment, the sedimentation rate may not be the same and the life of the lake be more than the expected life with this rate of sedimentation. The major cause of the sedimentation is the considerable

reduction in the forest cover. The present forest cover of about 20 percent dense forest is not adequate for the hilly catchment.

Mehta (2005) presented the cost benefit analysis of desilting of lakes and reported economic and ecological benefits of desilting. The case study of Udaipur reservoirs showed that with public participation, the expenses on desilting can be reduce to just 25 percent. The soil excavated can be used to increase the soil productivity. The dredging of highly nutritious upper layers of silt significantly arrests the processes of eutrophication and thus water quality gets improved.

Araujo (2006) presented the methodology to assess loss of reservoir volume by sediment deposition and its impact on water availability in seven representative semiarid watershed areas of Brazil. Water yield was computed using stochastic modeling for several reliability levels and water yield reduction was quantified for the focus areas. The yield–volume elasticity concept, which indicates the relative yield reduction in terms of relative storage capacity of the reservoirs, is presented and applied. Results showed that storage capacity was reduced by 0.2 percent year⁻¹ due to silting, that the risk of water shortage almost doubled in less than 50 years for the most critical reservoir, and that reduction of storage capacity had three times more impact on yield reduction than the increase in evaporation. Average 90 percent reliable yield–volume elasticity was 0.8, which means that the water yield in representative area is expected to diminish yearly by 388 L s⁻¹ due to reservoir silting.

Fiener and Auerswald (2006) pointed out that grassed waterways (GWWs) with large hydraulic roughness exhibit a great potential to reduce runoff, sediments and pollutants coming from agricultural watersheds. For conservation planning the knowledge of overall effectiveness and its seasonal variation is highly relevant. Their objectives were to (i) evaluate the seasonal variation in runoff reduction and sediment trapping in a GWW, (ii) identify the driving parameters and (iii) measure and analyze the seasonal variation of each of these parameters. Runoff and sediment delivery were measured between 1994 and 2001 in two paired sub watersheds, both optimized to reduce runoff and sediment delivery by an intensive soil conservation system within the fields. In one of the sub watersheds additionally a GWW (290 m long, 37 m wide) was established to further improve soil and water conservation. During the observation period it reduced runoff and sediment delivery by 87 and 93 percent, respectively. 70 percent of total outflow and 68 percent of total sediment output occurred between February and April, mainly controlled by watershed hydrology. Seasonal changes in GWW properties, namely soil water content and hydraulic roughness, had a minor effect. It was most notably in May and June, when available field capacity averaged 59 percent while

inflow was dominated by single heavy rain events (15 percent of total inflow). In general, the results indicate the high potential of GWWs for reducing runoff and sediment delivery, especially if combined with an intensive soil and water conservation system in the draining fields. For conservation planning, the least effectiveness at the end of winter should be taken into account.

2.5. Eutrophication

Pandey (2000) studied that Pichola and Fateh Sagar lakes of Udaipur in India are presently experiencing very high levels of algal eutrophication, mainly due to instability in the relevant ecological food-webs that resulted from interspecies predation and mortality at various trophic levels. In both lakes, very low zooplankton levels were observed, indicating high mortality and associated predation rates. He studied the impacts of varying zooplankton-mortality-coefficients on the dynamics of other ecological state variables phytoplankton, pelagic fish, benthic fauna, and demersal fish using a five-compartment aquatic ecosystem computer simulation model. Analysis revealed that phytoplankton levels show a strongly rising trend, especially in the case of Pichhola lake, while most of the other variables exhibit a declining trend. Ecological dynamics of the two lakes were found to be quite dissimilar. The most perturbed compartments were pelagic fish and demersal fish.

Gupta (2001) studied the hydro-chemical characters of lakes around Udaipur city for a period of five years. Except for the lake Udai Sagar, the salinity of water in lakes of Badi, Fateh Sagar, Pichhola and Swaroop Sagar is less than 750 micro Siemens per centimeter and fluctuates marginally in dry and wet period. The waters are Ca-Mg-HCO₃ type and have calcite saturation. The lake Udai Sagar is the most polluted, and exhibits eutrophic character along with the lakes Swaroop Sagar and Pichhola

Reddy (2004) gave a comprehensive view of the typical problems experienced in the better known lakes, their present environmental status and efforts being made to make them environmentally sustainable. He described that the lakes and reservoirs, all over the country without exception, are in varying degrees of environmental degradation. The degradation is due to encroachments, eutrophication (from domestic and industrial effluents) and silting. Based on available data, average annual loss in gross storage due to siltation is computed as 0.44 percent and, the annual loss in live storage as 0.31 percent. The reservoirs have created new ecosystems, supporting life growth even in dry period when the environment tends to be hard and inhospitable. It is generally noted that a forest far superior to the submerged original forest comes up along the rim or in the vicinity of the reservoir. There has been a quantum jump in population during the last century without corresponding expansion of civic facilities

resulting in lakes and reservoirs, especially the urban ones, becoming sinks for contaminants. He described various management techniques being used for restoration of lakes like treatment of watershed or catchment of lakes which not only brings in substantial improvements in the lake environment (reduction of silt, control of chemicals, and nutrients) but also results in the overall development of the community living in the catchment. Soil conservation measures, bank/slope erosion control measures, afforestation, drainage improvements, diversion of silt carrying channels away from the lake, control of sewage wastes, sewage interceptions and diversions and participation of people in watershed management measures have been widely adopted as effective management tools in all lake restoration projects.

Pandey and Pandey (2005) studied the influence of catchment modifications on two freshwater reservoirs (lakes) of Udaipur. The study, conducted between March 2004 and February 2005, reveals that of the many factors, nutrient flushing is an important determinant of lake ecosystem structure and functioning. Most of the nutrients found in lakes enter through rain drainage from the terrestrial catchment, direct discharge from anthropogenic sources and through atmospheric deposition from the aerial catchment. Nutrient laden waters often reflect the land use within the catchment. The study deals with run-off losses of carbon, sulphates and various species of nitrogen and phosphorus from different land-use categories in the catchment of Pichhola and Fateh Sagar lakes in southern Rajasthan. An effort was made to relate catchment nutrient import with water chemistry and biology of these lakes.

Sharma and Durve (2007) studied the eutrophication process in urban lake system of Udaipur. They started working on limnology of these reservoirs (lakes) since 1974 and are still working specially on the issue of planktons and productivity. On the basis of their own work and using references of many other researchers, they analyzed the changes in water quality, trophic status and biota of Udaipur lakes. The Udaipur lake are proceeding towards eutrophic conditions as evident from their primary productivity, plankton, depth of visibility, dissolved oxygen levels, total alkalinity, nitrates, phosphates and electrical conductivity. Initially oligotrophic water bodies harbour less diverse planktonic flora and fauna and as eutrophication advances, number of species increases reaching to certain optimum number to represent mesotrophic conditions. Many fold increase in gross primary production was noticed in all lakes. Algal mats of *Microcystis* (blue green algae) have become a perennial feature. The lake Pichhola is having irregular shore line girdled by hillocks, dense human habitation, hotel complexes, agricultural and forest land with scanty plantations. Excessive religious disposals coupled with sewage discharge accelerated eutrophication.

Sharma *et al.* (2007) pointed out that Udaipur lake system is degrading very fast primarily through cultural eutrophication. The lakes are rapidly getting silted due to extensive deforestation of the catchment. The entry of municipal sewage in the absence of a proper sewage system, multi point entry of domestic drains, open defecation practices, existence of hanging latrines, clothes, washing, bathing ghats, and the disposal of solid wastes in the lake basin have heavily loaded the reservoir's bottoms with organic debris. The chain of Udaipur lakes normally called Udaipur lake system forms an integral part of the east flowing river Berach and its tributaries in southern Rajasthan. This system is severely threatened with an unusual rapid aging and possible early extinction primarily owing to anthropogenic activity and is thus under stress of cultural eutrophication. Till the middle of last century, the lake system was a storehouse of varied aquatic fauna exhibiting rich biodiversity. During the last fifty years, there has been a progressive decline in this biodiversity and at present some of the fauna are on the verge of extinction or disappearance. The principal amongst these are the fishes Tot tor locally called Mahseer and other species- Labeo fimbriatus, L. bata and Xenentodon cancilla. Several planktonic species of clean waters are progressively giving place to new pollution tolerant species. It was reported that these lakes were fairly deep and transparent once upon a time and also had much bigger water spread than what is visible today. The shallowness of the lakes become more visible and evident during the last around sixty years since when the denudation of the surrounding hilly ranges began resulting in the excessive soil erosion. The eroded soil with silt from this catchment area finds its way to lakes to fill the lake basins. Presently, all the lakes have become so shallow that in the event of no or scanty rains over a few years, they totally dry up. The water spread areas of the lakes have also shrunk due to the encroachments by residents around the lakes, commercial establishments especially hotels and dumping of solid wastes in and around lakes.

2.6. Reservoir operations and eco technological management

Seok (1992) presented selective multi-objective operation policies of reservoirs system operation for Han river reservoirs system in Korea for four principal project objectives : Water supply and low flow augmentation, annual hydropower production, reliable energy generation and minimization of risk of violation firm water supply requirements. Additional objective such as flood control was also considered as fixed constraints.

Straskraba (1993) showed that eco techniques have to be used with the help of mathematical optimization models. Such models result, for the given ecosystem situation, in least cost and least secondary harm to the global environment

Ismail *et al.* (1997) proposed Chance Constraints LP model for optimization of the monthly operation of a real water supply system especially during periods of drought.

Marshall (1997) described that man made lakes are unnatural resources that create new physical and biological conditions. He stated that new information's learned about ecosystems would alter the management and operation of reservoirs in the future. The paper highlights ecosystem resource consideration for management of reservoirs in Kalmoth, Minnesota and Colorado river basins of United States of America.

Lund and Ferreira. (1999) reviewed a variety of derived single purpose operating policies for reservoirs in series and in parallel for water supply, flood control, hydropower, water quality and recreation. It is emphasized that such rules are useful for real time, seasonal and long term operations, and also for understanding the working of multi reservoir systems.

Needham *et al.* (2000) developed a deterministic optimization model which was applied to a three-reservoir system on the Iowa and Des Moines rivers to estimate the best possible operation of these reservoirs (with “perfect foresight”) and to determine whether or not tandem operating rules would provide appreciable benefits. The Iowa/Des Moines River Reservoir System consists of three reservoirs, i.e. the one on the Iowa River main stem and two on the Des Moines River main stem.. Authorized purposes for these reservoirs include flood control, low-flow augmentation, fish/wildlife, water supply, and recreation. The Rock Island District of the Army Corps is responsible for day-to-day decision making regarding reservoir operations. A linear programming (LP) model was developed that treats the flood-operation problem as one of finding a system-wide set of releases that minimize total system penalties for too much or too little release, storage, and flow. Essentially embedded in the LP model constraints is a simulation model that computes storage and downstream flows based on reservoir releases. The model constraint set includes continuity constraints for each reservoir and control point, along with constraints on reservoir release capacity, in each time period. The objective function includes penalties for too much or too little storage, release, or flow in each time period. The LP makes release decisions for all periods simultaneously, with perfect knowledge of the complete flow hydrographs. The results from this type of deterministic model have proven useful for inferring general reservoir system operational policies. Historical operation of a reservoir can be compared with the “optimal” operation determined by the model to identify possible shortcomings in current procedures; and questions regarding the operation of multiple reservoirs or the effects of changing physical aspects of the system can be addressed quickly.

Ram and Katakam. (2000), while underlining the usefulness of optimal operation of reservoirs systems, described a comparison of various optimization techniques and developed a real time simulation of reservoirs for maximizing the benefits like irrigation, hydropower and target storage levels.

Elizabeth *et al.* (2001) emphasized that reservoir managers must improve the management of existing resources and must adapt quickly to changing objectives and requirements. These management requirements translate into a need for river basin modeling tools that provide prescriptive results as well as allow the decision maker to easily modify operating policy, and physical and economic characteristics of a river basin. Due to the complexity of representing a multi objective reservoir system, most models in use have been descriptive. In addition, models developed for a particular river basin have been "hardwired" to represent operating policies and physical and economic characteristics. These hard-wired models have become costly and difficult to maintain, as they are not easily adapted to changing objectives and requirements. Optimization models can often provide prescriptive results. Summaries and reviews of multi objective reservoir optimization have commented on the continuing gap between research and practical application. This gap has been the matter of concern among all reservoir managers and is often attributed to models being overly simplified, rendering them unrealistic for operational scheduling. In addition, optimization may be difficult to use in operations because it requires optimization experts to setup, run, and/or interpret model results. General and modular optimization tools are currently used in daily operations of multipurpose reservoir systems, but these tools have limited prescriptive capability in terms of the complexity of policy objectives that they can incorporate, and also in their ability to optimize non-hydropower objectives.

Naidu (2002) developed a linear multi objective programming model and used constraint techniques to derive optimum releases for various purposes for Pench Hydroelectric Multipurpose project. The model was applied to three different cases of inflows related to most critical rainfall year, average rainfall year and maximum rainfall. The model was based on maximization of irrigation releases and maximization of hydropower production.

Jiaqi *et al.* (2003) presented an optimal mathematical model for the integrated operation of the seven reservoirs and hydropower stations in the upper basin of yellow river of China. The result showed that there was 5.89 percent increase in the average annual electricity generated by the hydropower station of all seven reservoirs.

Kracman (2005) developed a multistage stochastic optimization model using Linear Programming for operation of the High Land Lakes System, Texas. Three primary objectives were maximized in the model : (1) revenues from rice production, (2) recreation benefits associated with lake use, and (3) revenues from hydropower generation. Considering the uncertainty in the inflows, the model predicts optimum acreage levels, reservoir storage levels, reservoir releases, and other decisions, to maximize total expected benefits in the system.

Mehta (2005) described various structural and non structural techniques for ecological conservation and balance of urban reservoirs. He specified that in order to sustain the ecological, limnological and hydrological balance of the reservoirs; minimum 10 percent of the total storage capacity should be maintained as minimum conservation pool level in the reservoirs.

Tawatchai and Thana. (2005) developed programming for optimal operation policy of Kok-Ing-Nan Transbasin diversion Sirket Reservoir of Thailand. The study indicated that optimization increased the system annual net benefits by 50 percent.

Lund (2006) developed a simple drought storage allocation rule to minimize evaporative and seepage water losses from a system of reservoirs. Such a rule might have value during a prolonged drought, when the value of lost water is likely to be particularly high. Typically, concentrating water storage in one or a few reservoirs reduces overall water losses compared to "balancing" storage among reservoirs. Paradoxically, concentrating storage during a drought tends to minimize reservoir surface area available for recreation, increasing recreation losses even as it minimizes water losses.

Vogel *et al.* (2006) studied the relations among storage ,yield and instream flow for reservoirs. The study was conducted to evaluate the impact of reservoir operating rules on in stream flow properties. The study adapts the existing generalized Water Evaluation And Planning model (WEAP) to enable general explorations of relations between reservoir storage, in stream flow and water supply yield for a wide class of reservoirs and operating rules. Generalized relationships among these variables document the types of in stream flow policies which, when combined with drought management strategies, are likely to provide better solutions to the ecological and human negotiations for water for different size reservoir systems. In this study the concept of a seasonal eco-deficit/surplus is introduced for evaluating the impact of reservoir regulation on ecological flow regimes. It is no longer

possible to exploit water resources for human needs without taking into consideration the ecological flow needs.

Mirinda and Lowery (2007) studied juvenile densities relative to water regime in mainstream reservoirs of the Tennessee River, USA. The paper describes that the successful reproduction and development of strong classes of fish in storage reservoirs are commonly associated with reproductive seasons of high water level and extensive flooding. Responses to flooding are likely to be less pronounced or altogether different in mainstream navigation reservoirs that experience limited water level fluctuation. They examined existing data to identify aspects of the water regime that have detectable consequence on juveniles of selected type in a sequence of four reservoirs of the Tennessee River that exhibited relatively small annual rises. Empirical models relating density of selected age-0 centrarchids to water regime suggested that different water regimes had different effects on the study species, and presumably other species in the fish communities. Therefore, a diversity of water regimes rather than a rigid rule curve is more beneficial to the long-term permanence of the fish assemblages of the study reservoirs. Fixed rule curves produce drawdown zones devoid of vegetation consisting primarily of mudflats of limited ecological value to floodplain species, and maintenance of water levels within the rule curve force operational drops and rises that adversely affect littoral spanners. In developing water management plans, regulatory agencies should consider incorporating managed randomness into rule curves.

Parhi *et al.* (2007) developed a chance-constrained optimization model for design and operation of a reservoir for Ramiala reservoir in the Brahmani basin in Orissa ((India). In this study the available chance-constrained models for reservoir design and operation were modified and implications studied. The constraints limited the permissible range of reservoir releases and storage volumes, achieved with certain percentage of exceeding of inflows to the reservoir. To solve the proposed chance constrained model, the linear decision rule was applied. An operating policy meeting water supply (irrigation, hydropower, domestic and industrial), flood control, recreation, and environmental requirements by 2051 AD was developed; and, considering various possible sizes of the reservoir, and economic feasibility analysis based on probability distribution of monthly inflows was studied. The software package LINDO (Linear Interactive Discrete Optimizer), release 6.1, was used for determination of the optimum capacity of the Ramiala reservoir for four different conditions. The LDR for flood control, minimum storage, irrigation, domestic and industrial water supplies; and maximum release requirements were developed.

Sharma and Durve (2007) suggested various eco-technological measures for management of Udaipur Lake system. They pointed out that several remedial measures need to be implemented to restore the ecological balance of the lake system. These include: (1) diverting sewage out-falls, (2) preventing disposal of solid waste in the vicinity of lakes, (3) preventing bathing, defecation, washing of vehicle, clothes etc. in and on the banks of lakes, (4) replacing motor boats by paddle boats. The most important need is to reduce the silt inflow through wide-scale afforestation in the catchment. This particular measure is a long term one and hence needs to be supplemented immediately by the construction of silt traps at the inlets. The de-silting of lake basins would remove the anoxic layer of sediment. The de-silting is necessary at least at some vulnerable locations in the lake if it cannot be done for the entire lake bottom. Whenever the lake bottom is exposed, a uniform scrapping of deposited silt for at least 0.5 meter should be done. The desilting will dramatically restore lake water quality and biodiversity. Further, the silt traps constructed at the entry points of sediment laden water inlets would greatly reduce the sediment yield of the lakes. For non-point sources of sediment, the plantation of a gallery forest of 150 m should be developed, wherever possible, in the areas beyond F.T.L. This would prevent the large scale entry of eroded solid from non-point sources and also check direct human interference. The biological remedial measures are (1) Promoting restricted growth of nutrient removing plants like duckweeds and Eichhornia and their periodical harvesting (2) Introduction of phytophagous detritivorous, omnivorous fishes and also those which directly feed on organic debris. Eco technologically, these measures are referred as “bio manipulation”. Such measures cleanse water and tend to shift the trophic level to meso-tropic and oligotrophic side.

Montalvo *et al.* (2008) applied optimization algorithm known as Particle Swarm Optimization (PSO), to two case studies, i.e. the Hanoi water distribution network and the New York City water supply tunnel system. Both cases occur frequently in the related literature and provide two standard networks for benchmarking studies. Particle Swarm Optimization (PSO) is one of those evolutionary algorithms which, in spite of the fact that it has primarily been developed for the solution of optimization problems with continuous variables, have been successfully adapted in other contexts to problems with discrete variables.

2.7 Critique of Literature Review

The literature reviewed indicates that considerable literature and case studies are available on different aspects of reservoir hydrology, ecology and limnology. The literature on recharge and seepage from reservoirs is not very much available. The mathematical optimization techniques are applied for reservoir operations all over the world, but for our country, much emphasis is not given on this vital topic. Further, the ecological allocation criterion has not received significant consideration so far in deriving the reservoir operation rules.

3. MATERIALS AND METHODS

This chapter deals with general, topographical, geological and watershed characteristics of the study area; along with historical, morphometrical, ecological and environmental details of the selected surface reservoirs of upper Berach basin. The methodology adopted for assessing the reservoir inflow and outflow is also explained. At the end of the chapter, optimization model is formulated and various ecotechnological operation policies are framed.

3.1. STUDY AREA

The study area upper Berach basin is a sub basin of the Banas Basin. The Banas river originates from the eastern slopes of Aravali hills (Khamnor hills) in Kumbalgarh tehsil of Rajsamand district. It flows eastwards for about 512 km through Rajsamand, Udaipur, Chittorgarh, Bhilwara, Tonk, Jaipur, Ajmer, Dausa and Sawai Madhopur districts before joining Chambal river near village Khandar and Rameshwar of Sawai Madhopur District. The Banas Basin extends over an area of 47052 Sq.Km lying between latitudes 24° 18' and 27°14' N and longitudes 73°30' and 76° 58' E. The alignment of Banas river basin is north east to south west. It is bounded by the Luni basin in the West, Shekhawati, Banganga and Gambhir basin in the north, the Chambal basin in the east and the Mahi and Sabarmati basins in the south. The location map of Banas Basin is shown in Plate 3.1

The basin covers 9 districts of the state namely Udaipur, Rajsamand Chittorgarh, Bhilwara, Dausa, Jaipur, Ajmer, Tonk and Sawai Madhopur. Besides this, some part of Pali and Bundi districts also contribute to the Banas basin. Udaipur district has three river basins within its administrative boundaries viz. Mahi, Sabarmati and Banas (Anonymous,1996). The great Indian watershed separating Bay of Bengal and Arabian Sea passes through Udaipur. (Annexure A1)

Plate 3.1

3.1.1. Berach Basin

The Banas basin covers, wholly or partly, 19 hydro geological basins in Rajasthan, delineated by the Rajasthan State Ground Water Department, in accordance with surface catchment area considerations. The main tributaries of Banas are Berach on the right and Kothari, Khari, Dai, Mashi, Sohadara, Morel, Kalisil and Dheel on the left. River Berach originates from the north – east hill of Udaipur district, in the village Hiravato Ki bhagal (Bhutala) of Gogunda tehsil (GT sheet No. 45 H/9)at latitude $24^{\circ} 48' N$ and longitude $73^{\circ} 35' E$, at RL 800 meters above msl. It flows north east for about 157 km in Udaipur, Chittorgarh and Bhilwara districts before joining the Banas near Triveni of Bigod village at R.L. 360 meters in Mandalgarh tehsil of Bhilwara district (G.T. Sheet No. 45 O/4) . Its catchment area is 7899 Sq. Km. lies between latitude $24^{\circ} 29'$ & $25^{\circ} 14' N$ and longitudes of $74^{\circ} 36'$ and $75^{\circ} 2' E$. The main tributaries of Berach are Ayar, Wagon, Gambhiri and Oraj joining from right and left. The rainfall varies between 600 mm to 700 mm as shown by isohyets in the Plate 3.1

3.1.2. Upper Berach Basin

Berach river forms a part of the Ganga river system. Hierarchically, it is the fifth order drainage system of the river Ganga. The river Berach meets Ganga through the rivers Banas, Chambal and Yamuna. The catchment Area of river Berach is 7899 Sq. Km. out of which 2124 Sq. Km. is in Udaipur District. The upper Berach basin is a part of Berach basin having total geographical area of 1211 Sq.Km. It covers 227 revenue villages of Gogunda, Girwa, & Vallabhagar Tehsils. The present population , as projected on the basis of year 2001 census, is 0.6 million(Fig 3.1). The location map of upper Berach basin and its delineation on topographic sheet are shown in Plates 3.2 and 3.3.

Physiographically, the upper Berach basin can be divided into four geomorphic sub-regions:

1. Western hills.
2. Central hills
3. Inner Girwa plain of Ahar plain
4. Outer plain or Berach Katara plain.

Plate 3.2

Plate 3.3

The western hills are mostly extended in north-south direction. The average height of the area varies between 650 to 900 meters. The main tributaries of the basin including the river Ahar originate from these hills.

The central hills of the Berach basins extend, mainly, from north-west to south-east direction in the central part of the region. The inner Girwa plain is surrounded by western and central hills and its water is drained into the river Ahar. The important reservoir of the basin viz. Madar tanks, Badi, Fateh Sagar, Pichola, and Udai Sagar are located in this plain sub region. The lake Udai Sagar is situated at the margin of inner Girwa plain. The average height of the plain is 600 to 700 meters. Udaipur city and other habitations are developed in this region owing to its leveled topography, rich alluvial soils, availability of water and security of encircling hills (Anonymous,1995).

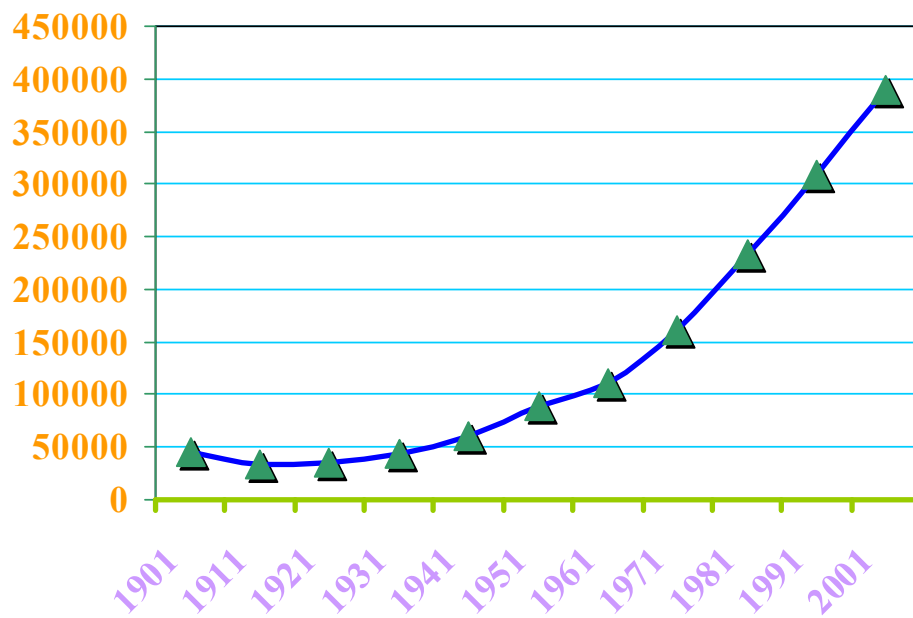


Fig. 3.1 : Population Rise in Udaipur

3.2 Udaipur and its Important Surface Reservoirs

The Udaipur reservoir (lake) system, arising out of river Berach and its tributaries, is an integral components of Upper Berach Basin. Udaipur was founded by Maharana Udai Singh of Mewar in 1559 A.D. Udaipur city is one of the most majestic and historic city. Every year some 0.8 million tourists (20 percent foreigners) visit this city, and tourism is the main source of employment and revenue generation. Udaipur city lies between $24^{\circ}33'$ and $24^{\circ}38'$ N latitudes and $73^{\circ}41'$ and $73^{\circ}45'$ E longitudes in a hilly and undulating terrain of Aravalli hill range. It is situated in the western part of India and in the southern region of Rajasthan, covering 61.10 Sq.Km. area. It is 577 m above mean sea level. It lies nearly 122 km north of Tropic of Cancer, and some 56 km north and 100 km west of the boundaries of Gujarat and Madhya Pradesh respectively. The Udaipur lake system, comprising of reservoirs Pichhola (Swaroop Sagar), Fateh Sagar, Badi ka Talab, Chhota Madar, Bada Madar, Chikalwas feeder, Lakhawali, Udai Sagar, Vallabh Nagar tank; and are primarily owned by the Water Resources Department of Government of Rajasthan. Location map and interconnection of selected surface reservoirs of upper Berach basin is shown in Plate 3.4.

3.3. Description of Interlinked Surface Water Reservoirs

3.3.1. Madar Reservoirs

These are the small reservoirs known as Bada Madar ($73^{\circ} 36' 28''$ E and $24^{\circ} 41' 1''$ N) & Chhota Madar ($73^{\circ} 36' 29''$ E and $24^{\circ}39' 46''$ N). They feed water to Fateh Sagar through Chikalwas feeder also known as Madar Nahar. (Plate 3.5). The catchment area of Bada Madar is 87 Sq. Km. and its gross capacity is 2.38 mcm. Its water spread is 0.8 Sq. Km. and total depth is 7.31 m. The length and width of the reservoir are 2.75 Km and 1.5 Km respectively.

3.3.2. Badi Reservoir

The reservoir Badi (Latitude $24^{\circ} 37' 7''$ N, Longitude $73^{\circ} 37' 29''$ E) also called as Jiyan Sagar, after the queen Jiyan Devi, was built in the year 1664 A.D. (Plate 3.6). The reservoir is a storage reservoir situated about 14 Km north of Udaipur city, near the village Badi. It is primarily an irrigational water body and has a water spread area of 1.46 Sq.Km. It receives water from the seasonal river Berach, and has a gross catchment area of 19.6 sq. km. The lake is roughly oval shaped with high rising hills on the three sides.

The maximum depth of the lake is 23 meters and the average depth is 10.6 meters. The deepest portion is at the dam site. The length and width of the reservoir are 2.285 Km and 0.642 Km respectively.

Plate 3.4

3.3.3. Pichhola Lake(Swaroop Sagar Reservoir)

It is the oldest among all the city lakes. The scenic views of Pichhola reservoir is shown in Plate 3.7. It was constructed at the time of Rana Lakha by a nomadic 'Banjara' and renovated and enlarged in 1559 A.D. by Rana Udai Singh along with the establishment of Udaipur itself. In 1795 A.D., during the reign of Maharana Bhim Singh, incessant rainfall destroyed the lake causing excessive floods in which half of the city was washed away. Pichhola is situated in the south western part of the city at $73^{\circ}40' 2''$ E longitude and $24^{\circ}35' 8.5''$ N latitude and its east-west extent is only a little more than its north-south extent viz. 3.6 and 2.0 km respectively. Deriving its name from the village of 'Pichholi' the lake is roughly triangular in shape with its base along the palace ridge, as shown in Fig. 3.2.

It accounts for a total water-body area of around 6.96 Sq.Km. (4.56 Sq.Km at FTL) and has gross, live and dead capacities of 13.676 mcm, 9 mcm and 4.676 mcm respectively. The gauge heights above and below sill level are 3.35 m and 5.2 m respectively. The maximum depth of the reservoir is 10.5 m at dam site. Its net catchment area is 146 Sq.Km. The rivers Kotra (Sisarma) and Amarjok (Bujhada) are the chief source of water supply to this reservoir.

3.3.3.1. Parts of Pichhola

Rang Sagar: This reservoir was constructed in 1668 A.D., has a length of 1030 m, width of 245 m and a maximum depth of 7 meters. It is one of the smallest lakes (water spread of 0.136 Sq.km.) along the western water-front of Udaipur, providing watery connection between Pichhola and Swaroop Sagar in south to Fateh Sagar in north. Rang Sagar lake was constructed by Amar Singh Badava and is also called 'Amarkund' after him.

Swaroop Sagar: Further southwards of Rang sagar is the ultimate part of Pichhola reservoir known as Swaroop Sagar. The reservoir Swaroop Sagar provides a waste weir for Pichhola. Moreover, Swaroop Sagar also link Pichhola and Rang Sagar, with the adjoining lake Fateh Sagar, through a canal. The canal is sometimes employed to draw water in Fateh Sagar during monsoon when Pichhola maintains a higher water level. On the eastern side of Swaroop sagar, is a masonry dam which has become a convenient site for open defecation. It has length of 800 m and width 250 m with water spread 0.2 Sq.km.

3.3.4. Govardhan Sagar

Situated at 10 km. of distance from Udaipur in south-west at $74^{\circ}42'$ E. longitude and $24^{\circ}34'$ N. latitude, it commands a gross catchment area of 1 Sq.mile and is endowed with gross capacity of about 0.255 mcm. It also receives water from Pichhola through a link canal.

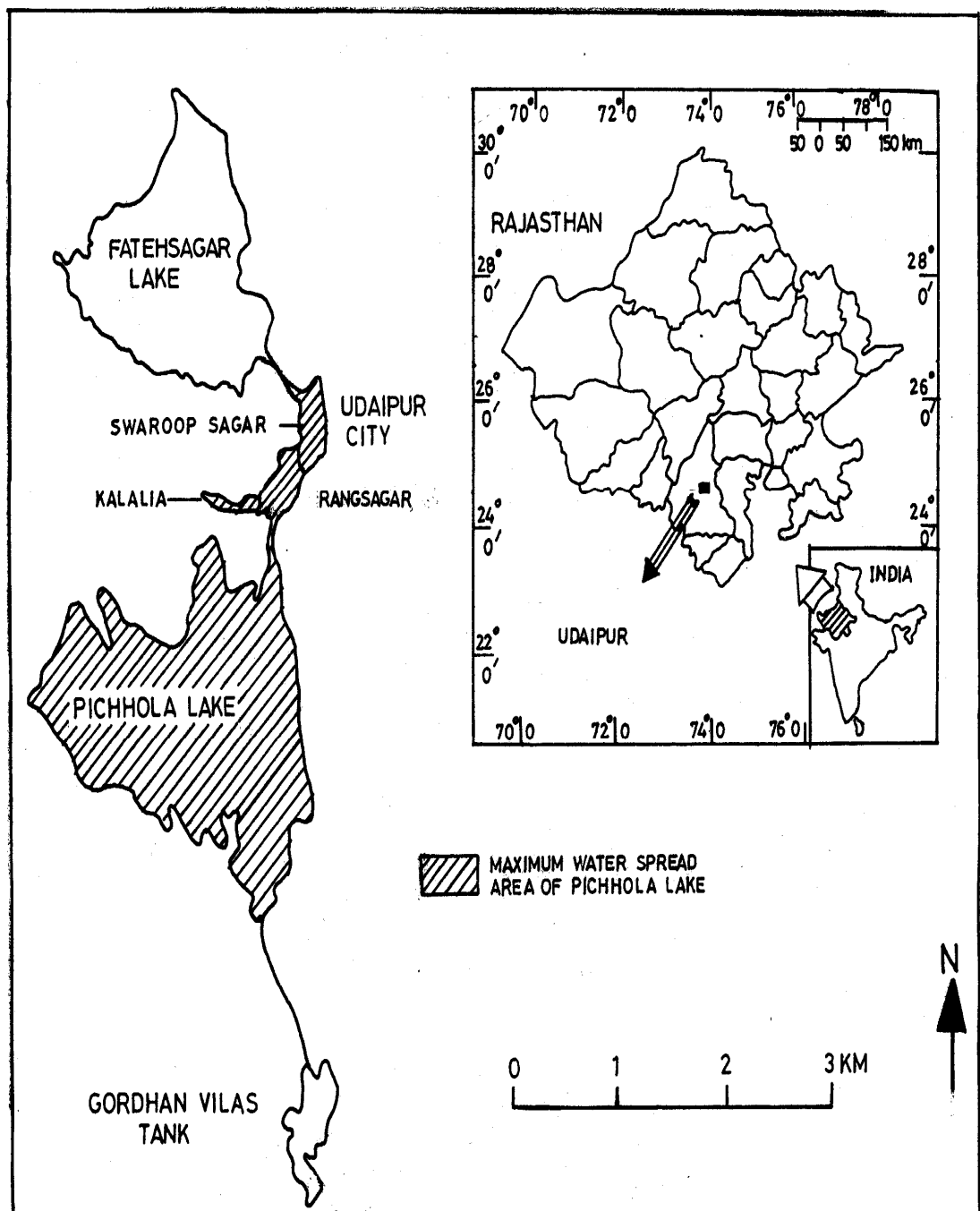


Fig 3.2 Location Map of Reservoir Fateh Sagar and Pichhola, Udaipur (Rajasthan)

3.3.5. Fateh Sagar Reservoir

The reservoir Fateh Sagar (Plate 3.8) occupies an important place in the social, economic and cultural life of Udaipur city. The reservoir is situated on 24°36' 16" N latitude and 73°40' 45" E longitude at 578 m altitude (above MSL) in the north western sector of the city. This pear shaped lake was constructed as a medium sized lake in 1678 A.D. Later on, in 1795 A.D., during the reign of Maharana Bhim Singh incessant rainfall destroyed the lake. It was renovated in 1889 A.D. by Maharana Fateh Singh. The dam is 720 m long and about 100m wide. Fateh Sagar reservoir stretches 2600 m in north-south and 1800 m in east-west directions, covering total water spread of nearly 4.0 Sq.km (2.56 Sq km at FTL) and has a maximum depth of 11.5 m. It commands a total catchment area of about 43.25 Sq. km. Its gross, live and dead capacity of 12.09 mcm, 7 mcm and 5.0 mcm respectively, evidently lower than that of Pichhola. The reservoir is mainly fed by Chikalwas (Madar) feeder, from Madar reservoirs built across river Ahar and are located at a distance of 8 Kms north of the reservoir. It also receives overflow of the Badi reservoir.

3.3.6. Udai Sagar Reservoir

The reservoir Udai Sagar (Plate 3.9) is situated near the village Bichari. at Latitude 24° 34' 41" N longitude and 73° 49' 31" E and is about 15 km from the city of Udaipur. This reservoir is named after Maharana Udai Singh, the founder of the city of Udaipur. The Reservoir was built in the year 1559 A.D. This reservoir forms the last lake in the chain of Udaipur lake system. The major part of its water is supplied for irrigation and for industrial needs of private sector company M/s Hindustan Zinc Limited, a unit of the Vedanta group.

The reservoir was constructed by building a masonry dam on the river Berach. It has a water spread area of 5.20 Sq. Km at full tank level (FTL). The gross capacity is 31.15 mcm while the dead and liver storage are 3.54 mcm and 27.61 mcm respectively. The length and width of the reservoir are 4.2 Km and 2.75 Km respectively. The catchment area is spread over the western side of the lake and the gross catchment is 479.19 Sq.Km. which includes the catchment of other reservoir in the chain lake system of Udaipur. The free catchment area of Udai Sagar alone is 196.84 Sq.Km. The bottom is silty because of continuous sedimentation during the last about 400 years. The main source of water for the lake is a tributary of the river Berach popularly called Ahar which passes through the city of Udaipur and joins Udai Sagar near the village Sukha Naka. Besides this, several small seasonal rivers and streams arising from the surrounding hills also enter the lake. The greatest depth is Udai Sagar lies at the dam site and is 6.1 m. The reservoirs indicates a tendency of shallowness.

Plate 3.5

Plate 3.6

Plate 3.7

Plate 3.8

Plate 3.9

3.4. Stratigraphy

The area of study comprises of Aravalli Supergroup rocks of lower proterozoic age . The main city area lies on soft and cleaved metamorphic rocks of phyllite, schist and metagraywacke. The catchment area lies in the west of the lakes, which is mainly fed by the drainage of Aravalli hill ranges (Anonymous, 2004, c). The rock of upper catchment area is composed of phyllite, schist, basic volcanics and pyroclastics with enclaves of metaconglomerate and dolomite marble. The drainage is mainly controlled by the lineaments (fractures) cutting across the hill ranges. The stratigraphy with major rock types of the area is given in Table3.1.

Table 3.1 : Stratigraphy and Geological Formations Around Udaipur City

Lower Proterozoic	Synorogenic granite and gneiss		
	Aravalli Supergroup	Nathdwara Group	Phyllite, Chlorite mica schist
		Badi Talab Group	Chlorite phyllite / meta tuff
			Basic volcanics And pyroclastic with enclaves of metaconglomerate and marble
			Quartzite, pebbly arkose and metaconglomerate
		Udaipur Group	Phyllite with enclaves of dolomite and chert
			Phyllite, metagraywacke and mica schist
			Quartzite and meta phelite
			Phyllite and metagraywacke

Source : RRSSC- Jodhpur, 2004

3.5. Morphometric and Watershed Characteristics of Udaipur Reservoirs

The watersheds of Chota Madar, Bada Madar, Badi, Pichhola, Fateh Sagar, Udai Sagar are located in Aravali ranges and cover many revenue villages of Girwa, Badgaon and Gogunda Panchayat Samitees. Some of the villages situated near the ridge lines are partly covered in the watershed. The general slope of the wathersheds is from S-W to N-W directions. Topography is very undulating. Important morphometric features and agriculture details of Udaipur reservoirs are shown in Table 3.2. The Map of Catchment area of Udaipur reservoirs is shown in Annexure A2

Table 3.2 : Morphometric Features & Irrigation Details of Reservoirs

	Bada Madar	Badi	Fateh Sagar	Pichhola	Udai Sagar
Longitude	73° 36' 28" E	73° 37' 29" E	73° 40' 45" E	73° 41' 2" E	73° 49' 31" E
Latitude	24° 41' 1" N	24° 37' 7.1" N	24° 36' 16" N	24° 35' 8.5" N	24° 34' 41" N
Catchment Area	87.00 Sq.Km	19.06 Sq.Km	43.25 Sq.Km	146.06 Sq.Km	479.00 Sq.Km
Gross Capacity	2.38 mcm	10.5 mcm	12.09 mcm	13.676 mcm	31.149 mcm
Live Capacity	2.26 mcm	7.25 mcm	7.00 mcm	9.00 mcm	27.6 mcm
Water Spread	0.8 Sq.km	1.46 Sq.km	2.59 Sq.km	4.60 Sq.km	5.60 Sq.km
Depth Above Sill	7.31 m	9.90 m	3.96 m	3.35 m	7.31 m
Depth Below Sill	0.0 m	14.93 m	6.70 m	3.04 m	6.00 m
Gross Command Area (GCA)	306 ha.	298 ha.	803 ha.	258 ha.	5094 ha.
Culturable Command Area (CCA)	281 ha.	251 ha.	667 ha.	238 ha.	4655 ha.
Intensity of Culture (ICA)	264 ha.	162 ha.	405 ha.	202 ha.	1947 ha.
Maximum Irrigation	373 ha. in the year 1976-77	191 ha. in the year 1978-79	319 ha. in the year 1977-78 Water reserved for drinking after 1986	125 ha. in the year 1978-79 Water reserved for drinking after 1986	2510 ha. in the year 1992-93

Source : Water Resources Department, Govt. of Rajasthan.

3.5.1. Badi Watershed

The total area of Badi watershed is 1906.55 hectare out of which 29 percent area is under cultivation and 71 percent area is under private and government non-arable and farms lands . The soils of the area are fine loam, silty-loam, loam, rocky and gravelly sandy clay loam soils. The average slope of area is between 5 to 50 percent. The cultivation is being done on deep to moderately deep soils having depths 50 to 75 cm and infiltration rate between 3.6 to 6.8 cm/hr. It is categorized in hydrologic soil group B. The cultivable land of the watershed is having shallow soils ranging in depths from 25 to 50 cm with infiltration rate between 1.5

to 2.8 cm/hr. Due to overgrazing and poor vegetative cover the hydrological condition of watershed is poor (Kumar, 2007).

The annual runoff for Badi as well as Chhota Madar watershed varied from 2.08 mm (0.71 percent) in year 1987 to 326.20 mm (37.32 percent) in 2005. In 1987, though 291.80 mm rainfall was received but the distribution of rainfall was erratic and maximum one day rainfall was received 23.9 mm when the watershed was dry. In the year 1978, 29.61 percent of runoff was observed mainly due to 303.7 mm of rainfall in ten consecutive days only. In the year 2005 highest runoff was calculated mainly due to heavy rainfall in three consecutive months with maximum one day rainfall of 105 mm. Roy (1998) calculated 29.68 percent (336.23mm) runoff for the year 1973.

3.5.2. Chhota Madar watershed

The total area of Chhota Madar watershed is 2987.23 ha. The soil is fine loam, loam, rocky and gravelly sandy clay loam soil. The depth of soil varies from 25 to 75 cm with infiltration rates between 1.5 to 6.8 cm/hr. On the basis of the depth of the soil and infiltration rates, the land under cultivation is categorized as hydrologic soil group B. The shallow soils which accounted for 67 percent of the area and are placed under hydrologic soil group C. The weighted curve number of the watershed for normal condition is 83.5 and the corresponding curve number values for AMC I and AMC III conditions worked out is 67 and 93 respectively.(Kumar, 2007).

3.5.3. Bada Madar Watershed

The total area of Bada Madar watershed is 8780.48 ha, which contains 2252.82 hectare cultivable, 5727.83 hectare pasture and 798.83 hectare forest land. The land under cultivation is moderately deep to deep with depth varying from 50 to 75 cm. The soils is fine loam with an infiltration rate of 1.5 to 6.8 cm/hr. The area under cultivation is categorized as hydrologic soil group B whereas the area under pasture and forest is categorized as hydrologic soil group C. The hydrologic conditions of the watershed are found fair to good.

The mean annual runoff of the watershed for thirty years was found to be 13.89 percent. The lowest runoff obtained was 0.28 percent (0.82 mm) in the year 1987 whereas the highest runoff obtained was 35.10 percent (306.82 mm)in the year 2005. (Kumar, 2007) . Roy (1998) calculated 28.14 percent (318.78 mm) runoff for the year 1973.

3.5.4 Fateh Sagar watershed

The total area of watershed is 4325.35 hectare of which 1049.47 hectare is under cultivation. The soils of the Fateh Sagar watershed on which cultivation is being done is loam clay loam ranging in depth from 20 to more than 100 cm with infiltration rates of 3.6 to 7.6 cm/hr. The soil of cultivable land is categorized as hydrologic soil group B whereas the soil of non arable land is categorized as hydrologic soil group C(Kumar,2007).

The annual runoff of Fateh Sagar watershed calculated by SCS curve number method was obtained by summing up the daily runoff of the year. The runoff up to 10 percent was observed in 11 years, 10 to 20 percent in nine years and 20 to 36 percent in remaining 10 years. The lowest runoff obtained was 0.39 percent (1.14 mm) in the year 1987 whereas the highest runoff obtained was 36.29 percent (317.18 mm)in the year 2005. (Kumar, 2007). Roy(1998) calculated 29.40 percent (333.03 mm) runoff for the year 1973.

3.5.5 Pichhola –Swaroop Sagar Watershed

The total area of this watershed is 14610.63 hectare in which mainly fine loam, loam, gravelly sandy clay loam and rocky soils are there. The parts of the watershed which have moderately deep to deep soils generally ranging from 75 to 100 cm are under cultivation which covers area of 5240.3 ha, with soil slope varying from 1 to 15 percent. The infiltration rates calculated is 1.4 to 5.2 cm/hr. Most of the remaining portion is rocky formation having slopes varying from 30 to 50 percent. This part of the watershed is under pasture. The area which is under cultivation is placed under hydrologic soil group B and the area under pasture is placed under hydrologic soil group C (Kumar,2007).

In the year 1987, the runoff from watershed was 0.19 mm which is nearly zero whereas maximum runoff of 301.93 mm (34.54 percent) was observed in 2005. The mean annual runoff of thirty years was found to be 12.18 percent. It was observed that in 1976, despite 649.80 mm of rainfall, only 88.90 mm (6.88 percent) runoff was observed, whereas in 1985 only 658.05 mm of rainfall produced 228.35 mm (29.06 percent) of runoff. It was mainly because runoff producing storms were few in 1976. But, in 1985, there were continuous rainfalls of high intensities and long durations. Roy(1998) calculated 26.07 percent(295.35 mm) runoff for the year 1973.

3.5.6. Udai Sagar Watershed

The total area of Udai Sagar watershed is 25330 ha. out of which 6330 hectare falls under urban area. Sandy loam and silty loam soils were found in varying depths ranging from 25 to 100 cm. The infiltration rate of the soil were found to vary from 1.5 to 8 cm/hr. The hydrologic condition of the watershed was found to be poor (Roy, 1998). The lowest runoff obtained was 0.39 percent (1.14 mm) in the year 1987, whereas highest runoff obtained was 36.29 percent (317.18 mm) in the year 2005 (Kumar, 2007).

3.6. Status of Pollution

Almost all surface water reservoirs of upper Berach basin are facing severe threat of nutrient rich sedimentation because of degradation of their respective catchment areas. The changes in land use and degradation of land in the catchment areas have disturbed the entire hydrological balance of the reservoirs. The vegetative cover in upper Berach basin is very poor. The high velocity runoff, coming from barren hills, human habitations, agricultural fields and industrial areas is damaging the delicate eco-balance of the reservoir ecosystems.

Some of the major changes in the land use are forest-thinning, grazing, cultivation, agriculture, industrialization and other such human interventions. In tropics like Udaipur, where light and temperature are generally optimal, nutrient status has become the major determinant of aquatic ecosystem properties. Terrestrial systems are contributing to the surface waters by adding nutrients through run-off. Such additions are not only regulating the water chemistry and biology, but are also affecting microbial biomass dynamics at land-water interface. This in turn, regulates nutrient pulsation in lake water and consequently phytoplankton bloom (Pandey and Pandey 2005)

Further, in Udaipur reservoirs, not all the nutrients that nourish aquatic ecosystems are derived from terrestrial catchment; the atmospheric depositions are also contributing to the deterioration process. There are wet and dry depositions of organic carbon, P and N in Udaipur reservoirs.

3.6.1. Eutrophication and Deterioration of Water Quality

Eutrophication, which denotes nutrient and productivity status of a reservoir, is a serious problem in almost all reservoirs. The human interferences like deforestation in the catchment areas, sewage inflow and overexploitation of water, deep below the sill levels , (Plates 3.10) have caused cultural eutrophication, seriously affecting the ecological, biological, social, economic and cultural fabric of Udaipur. Pichhola ,Fateh Sagar and Udai

Sagar reservoirs are significantly suffering from eutrophication which is evident from the symptoms such as foul odours, mats of algae and macrophytes, algal blooms etc .

The studies on reservoir ecosystem health by Sharma & Durve (2007) and Central Pollution Control Board indicate the eutrophic status of reservoirs (Table 3.3). There is an increasing tendency in surface water temperature which may be attributed to continuous shallowing of the reservoirs. There is a considerable decline in minimum as well as maximum values of depth of visibility as measured by Secchi disc. Depth of visibility gives first hand information regarding water quality and trophic assessment.

Dissolved oxygen (DO) is an important limnological parameter indicating status of water quality and organic production of the reservoirs. Survival of aquatic organisms, especially fishes, depends upon the level of dissolved oxygen in water. The DO values were relatively high (4.4 -11.00 mg/l) during the period of 1974-75, but now they have reduced to the range of 0.5 to 7.8 mg/litre. Low concentration of oxygen in reservoir water sets up anaerobic conditions. Further, the process of decay of organic matter releases the free carbon dioxide and it causes depletion of oxygen which usually results in foul smell and fish mortality. (Plate 3.11)

Biochemical oxygen demand, electrical conductivity, hardness, total phosphates, nitrates, chlorides, sulphates, silicates and total alkalinity have also increased during the last 30 years . The concentration of chlorides speaks of organic pollution due to domestic sewage. The higher concentration of nitrate and phosphate in the reservoirs further supports that the source of pollution is domestic sewage, animal wastes and farm land runoff.

Excessive Phytoplankton population indicates the higher organic and bacterial load. The excessive growth of algae, *Hydrilla verticillata*, *Potamogeton*, *Ceratophyllum demersum*, *Vallisneria spiralis*, *Ipomea aquatica*, Water Hyacinth etc create many problems such as undesirable odour, taste and colour. They clog the filter and retard the water flow. The most serious indicators are the presence of faecal coliforms which indicate that the waters are not suitable even for bathing purpose.

Table 3.3 : Changes in Limnological Parameters of Reservoirs of Upper Berach Basin

S.NO.	Parameters	Year 1974-75	Year 2004-05	Year 2005-06
1	Water Temperature	13.2 ⁰ -29.5 ⁰ C	15.8 ⁰ -33.9 ⁰ C	
2	Depth of visibility	48-136 cm	17.5-119 cm	
3	pH	7.7-8.7	8.35-9.30	7.7-8.2
4	Dissolved oxygen	4.4-11.00 mg/l	0.5-7.8 mg/l	
5	BOD	57.00 mg/l	168.00 mg/l	
	COD			12 - 24 mg/l
6	Electrical conductivity	190-700 μ mhs	420-1590 μ mhs	
7	Hardness	79.18-83.36 mg/l	101.20-208.00	126-244 mg/l
8	Total phosphates	0.002-1.40 mg/l	0.18-9.66 mg/l	
9	Nitrate (Nitrogen)	0.20-0.70 mg/l	0.34-1.88 mg/l	
10	Chlorides	18.13-27.22 mg/l	54.98-189.90 mg/l	
11	Sulphates	6.012-33.066 mg/l	12.54-30.07 mg/l	
12	Silicates	3.00-23.7 mg/l	1.4-24.56 mg/l	
13	Total Alkalinity	125-138.87 mg/l	162-286 mg/l	112-182 mg/l
14	Phytoplankton (Diversity)	82 species	40 species	
15	Phytoplankton (Biomass)	280-8030 cells/ml	1440-10580 cells/ml	
16	Zooplankton (Biomass)	3-1657 no./l	474-3480 no/l	
17	Zooplankton (Diversity) No. of species & Mechanic's index values	41,5.29233	23,2.022	
18	Gross Primary production	0.03-5.09 gc/m3/day	5.04-20.43 gc/m3/day	
19	Total coliforms			4200-7600 MPN/100ml
20	Feecal Coliforms			1300-4200 MPN/100ml
		For Pichhola and Fateh Sagar Reservoirs	For Pichhola and Fateh Sagar Reservoirs	For Pichhola, Fateh Sagar and Udai Sagar Reservoirs
	Source :-	Sharma et al,2007	Sharma et al,2007	CPCB,2006

Plate 3.10

Plate 3.11

Many-fold increase in gross primary production is noticed in all these reservoirs. Udaipur reservoirs used to harbour good ichthyofauna, consisting 42 species of fish including Mahseer and all major carp fishes. But now only 17 species of fish are surviving. The study conducted by Sharma and Durve(2007) shows that the total suspended solids (TSS) and total dissolved solids (TDS) are on increase along with the values of electrical conductivity, and they stand at around 40 ppm for TSS, more than 400 ppm for TDS, and around 700 μ mhos for EC. The higher values are obtained in Pichhola, which is more eutrophic than Fateh Sagar, Badi and Bada Madar. The pH of the water is gradually tending towards higher alkaline side (up to around 8.8), and the BOD values are also as high as 11.2 to 15.40 ppm. The orthophosphates in Pichhola range between 1.70 to 6.70 ppm which is many fold higher than the recommended critical level of 0.02 ppm dissolved phosphate.

Ammonia nitrogen and nitrite nitrogen are 0.46 to 0.48 ppm, and 1.166 ppm respectively. The concentration of chlorides, which indicate organic pollution was found around 150ppm. The dissolved organic matter ranges between 4.18 to 10.54 ppm.

The bacteriological status of the reservoirs is a matter of serious concern as the MPN values are greater than 2400 Nos./100 ml for total and faecal coliforms. Further, occurrence of streptococci, citrobacter, strepto faecalis, ova of ascaris, cysts of *E. histolytica*, Giardia and Trichuria trichuria have been located in Udaipur reservoirs. All the above parameters indicate an alarming situation of contamination in drinking water lakes of Udaipur. Using average water clarity values, the scale developed by Sharma and Durve for Rajasthan's reservoirs classify Udaipur reservoirs in a eutrophic category.

The deteriorating water conditions in the lake was solely reflected in the change of faunal and micro flora patterns of the lakes. Highly sensitive planktonic organisms such as species of Aecella and Centrophyx have become lesser in counts while the rotifers of Brachionus genus are dominating with counts of 400.8 ind/ml. In the case of microalgae, Myxophyceae (especially the genus Microcystis) has become dominant. From amongst macrophytes, the floating flowering plant Eichhornia or water hyacinth occasionally develops dense growth at times, over the entire water surface. There are all the indications of higher nutrient load, degrading water and sediment conditions.

Among all the aforesaid reservoirs, lake Badi is in a relatively good ecological condition which is evident from the water quality analysis done by Central Pollution Control Board in the year 2005 (Table 3.4). The lake Badi situated, within the tropics, receives enough solar energy along with conducive temperatures and rainfall. The chemical parameters of the lake indicate an alkaline, nutrient rich, moderate to hard water, and it is suitable for

aquaculture. Udai Sagar is the most polluted since it receives the entire untreated domestic and industrial waste water of Udaipur. The high values of TDS, COD, and alkalinity indicate the worst state of Udai Sagar reservoir. The analysis done by Tetrattech company (Anonymous, 2007) in the year 2007 (Table 3.5) indicates that pollution level of Pichhola and Fateh Sagar has increased as reflected from the values of TDS and COD.

Table 3.4 : Water Quality of Selected Reservoirs of Upper Bearch Basin(Year 2005)

Reservoir	pH	TDS (ppm)	COD (ppm)	Alkalinity (ppm)	Hardness (ppm)	Total Coliform (MPN per 100ml)	Feacal Coliform (MPN per 100ml)
Badi	8.01	176	4	112	110	0	0
Fateh Sagar	7.83	180	12	122	126	7600	4200
Pichhola (Main)	7.7	250	16	134	130	4200	1300
Udai Sagar	8.2	478	24	182	244	6200	2000

Source : CPCB, Regional Office, Bhopal

Table 3.5 : Water Quality of Selected Reservoirs of Upper Bearch Basin (Year 2007)

Reservoir	TDS (ppm)	BOD (ppm)	COD (ppm)	Inorganic Phosphosphate (ppm)	Total Phosphate (ppm)	Nitrate (ppm)
Pichhola (Main)	333.12	23.42	59.2	1.48	1.68	1.4
Fateh Sagar	326.546	20.8	53.43	1.18	1.5	2

Source: National Lake Conservation Plan Report for Udaipur Lakes, Tetrattech Report,
March 2007

Apart from all the above factors, contributing to the deterioration of reservoir ecosystems, the foremost factor is over-exploitation of surface and sub-surface waters of reservoirs. The un-planned extraction, without considering the importance of reservoir ecology, is resulting in regular drying of lakes. The self purifying capacity of these reservoirs has almost vanished, and this is further enhancing the death process of these reservoirs.

3.7. Interbasin Transfer of Water from Sabarmati & Mahi Basins

To transfer the additional surplus water of adjoining Sabarmati basin to Berach basin, there are two projects namely Dewas scheme and Mansi Wakal Scheme. (Anonymous, 2004,b). Dewas scheme has 4 stages and Mansi Wakal scheme has 2 stages. Dewas project stage 1 was constructed in the year 1973-1974 and it diverts 3.54 mcm water to Pichhola reservoir. Mansi Wakal project stage I has also been completed recently and it is providing 36 mld drinking water to Udaipur. The water of Mansi Wakal stage I is supplied directly into drinking water distribution system of Udaipur city. To maintain the water levels in Pichhola, Fateh Sagar and Udai Sagar reservoirs, it has been decided by the state government to implement the remaining stages of Dewas scheme. Accordingly, the work on Dewas II stage is in progress and this project will divert 13.5 mcm water to Pichhola and Fateh Sagar at 75 percent dependability. The details of various interbasin transfer projects in Sabarmati basin are shown in Table 3.6 and Plate 3.12

3.8. Status of Drinking Water Supply to Udaipur

Presently Mansi Wakal I Scheme is providing 23 mld water at 95 percent dependability, out of which 30 percent share is reserved for Hindustan Zinc Limited. The Jai Samand reservoir (gross capacity 424 mcm) provides 24 mld ensured water supply to Udaipur and availability from public ground water sources is 10 mld water. Besides people extract ground water from around 40,000 domestic tube wells.

The Dewas II Scheme, at present under construction, will be completed by the year 2010. This scheme will provide 11 mld water at 95 percent dependability. The proposed Dewas III & IV Schemes and Mansi Wakal II Scheme, if implemented, will provide 110 mld water at 95 percent dependability.

Plate 3.12

Table 3.6 : Interbasin Transfer Schemes in Upper Berach Basin

Sr. No.	Basin	Schemes	Year of Construction	Status	Yield at Various Dependability (mcm)			
					50%	75%	90%	95%
1.	S A B A R M A T I	Dewas I	1973	Completed	4.78	3.54	2.54	1.186
2.		Mansi Wakal I	2005	Completed	21.60	15.30	9.68	8.55
3.		Dewas II (Madri & Akodra)	Work started in the year 2006	Under construction	15.56	11.52	8.27	3.86
4.		Dewas III	Survey work initiated	Proposed	17.00	10.73	7.23	5.82
5.		Dewas IV	Survey work initiated	Proposed	17.80	11.22	7.58	6.00
6.		Mansi Wakal II (III)	Proposed	Proposed	71.00	50.29	32.81	28.10
7.	Jaisamand (Mahi Basin)	Jaisamand Pumping Scheme	1990	Operational	24 mld (8.76mcm yearly) water is pumped daily for drinking water supply to Udaipur			

Source : Water Resources Department, Government of Rajasthan.

3.9. Delineation of Interlinked Surface Reservoirs of Upper Berach Basin

Upper Berach basin was delineated using general topographic sheets 45 H/9, 45H/10 and 45 H/11., scale 1:50000, collected from Water Resource Department, Government of Rajasthan. The interlinked reservoirs and interlinking channels were identified. The catchment areas of individual reservoirs were delineated and calculation of areas was done using software ARC GIS 9.2 and digital planimeter.

3.10. Submergence and Capacity Curves

The capacity curves were obtained from the Water Resources Department, Government of Rajasthan. The depth area curves (i.e submergence curves) are not available, except for the Pichhola reservoir. The reservoirs were almost dry in the period 1997-2004 and it was observed by the researcher that the reservoirs are now almost of flat bottom because of deposition of sediments in depressions. Therefore it was assumed that the submergence area will vary with depth in the same proportion as capacity values vary with depth.. With this assumption, submergence curves for all reservoirs were drawn. (Fig. 3.3 to 3.7)

3.11. Rainfall Details

Yearly rainfall data for thirty eight years were collected from five stations viz. Gogunda, Madar, Udaipur, C.T.A.E and Udai Sagar. The rainfall data from Udaipur, Gogunda and C.T.A.E stations are available from the year 1970. The Udai Sagar and Vallabh Nagar stations were established in the years 1994 whereas the Madar station was established in the year 2002; hence, rainfall data from these stations are not available from the year 1970. The average yearly rainfall of upper Berach basin is 600.67mm. It was estimated by taking an average of the yearly rainfall of the above five stations. (Table 3.7)

India Meteorological Department (IMD, 1971) classified the drought years as per percentage rainfall deficiency. IMD classified the drought years into slight, moderate and severe drought. As per percentage, rainfall deficiency lies between 11 percent to 25 percent, 25 percent to 50 percent and more than 50 percent respectively. Walker (1912) classified the drought as large, serious, and disastrous for the rainfall deficiency lying between 30 percent and 45 percent, 45 percent and 60 percent, and above 60 percent of the normal annual rainfall respectively.

Subrahmanyam and Subramaniam (1964) used the population mean μ and the standard deviation σ of the annual rainfall to classify the drought years. The years with rainfall between μ and $\mu - 1/2 \sigma$, $\mu - 1/2 \sigma$ and $\mu - \sigma$, $\mu - \sigma$ and $\mu - 2 \sigma$ and lesser than $\mu - 2 \sigma$ are termed as moderate, large severe and disastrous drought years respectively. The yearly rainfall data of Upper Berach Basin are classified as per the aforesaid drought classifications.

Table 3.7: Yearly Rainfall in Upper Berach Basin

S.N	Year/Station	Udaipur	Gogunda	CTAE	Madar	Udai Sagar	Vallabh Nagar	Average (mm)
1	1970	781	848	766.2				798.400
2	1971	469.4	432	458.3				453.233
3	1972	365	299.1	393.6				352.567
4	1973	1096.2	1575	1145.3				1272.167
5	1974	397	456	467.7				440.233
6	1975	696.9	898	607.3				734.067
7	1976	603.4	600	696.2				633.200
8	1977	488.9	482	560.1				510.333
9	1978	740.2	758	819.6				772.600
10	1979	577.9	503	551.9				544.267
11	1980	622.6	400	769.4				597.333
12	1981	713.8	764	551.4				676.400
13	1982	617	542.8	595.9				585.233
14	1983	688.2	690	1014.5				797.567
15	1984	697	588	547				610.667
16	1985	727.8	765	588.3				693.700
17	1986	303	411	383.9				365.967
18	1987	200.5	275	383.1				286.200
19	1988	549.4	642	467				552.800
20	1989	677.6	520	895.2				697.600
21	1990	867	793	666.4				775.467
22	1991	422.6	467	615.3				501.633
23	1992	779	827.5	727.3				777.933
24	1993	412	481	353.1				415.367
25	1994	768	873	778.9		457	731	719.225
26	1995	431	443	333.7		292	438	374.925
27	1996	612	634	636.4		752	681	658.600
28	1997	613.7	618	673.9		464	598	592.400
29	1998	646	585	669.2		434	523	583.550
30	1999	410	384	412.9		353	547	389.975
31	2000	447	380	439.7		398	352	416.175
32	2001	493.6	715	531.2		590	639	582.450
33	2002	400	345	365.3	389	306	372	362.883
34	2003	587	690	497.4	611	422	549	559.400
35	2004	578	425	601	560	426	664	542.333
36	2005	815	832	945.2	862	803	603	810.033
37	2006	856	901	984.3	900	811	1053	917.550
38	2007	452	500	494.3	449	441	490	471.050

Source: Water Resources Department, Government of Rajasthan & CTAE Udaipur.

Fig. 3.3 to 3.7

Fig. 3.3 to 3.7

Fig. 3.3 to 3.7

Fig. 3.3 to 3.7

Fig. 3.3 to 3.7

3.12. Reservoir Losses

The reservoir losses include evaporation and seepage losses. Many methods exist for either measuring or estimating evaporative losses from free water surfaces. Evaporation pans provide one of the simplest, inexpensive, and most widely used methods of estimating evaporative losses. Evaporation from a free surface is related to pan evaporation by a coefficient applied to the pan readings. The average pan evaporation data, based on thirty five years record, was collected from agro-metereological station of C.T.A.E and was converted into open water evaporation by multiplying with correction factor of 0.7 (annexure) using the equation

$$Erw = kw * ET_0 \dots\dots\dots(3.1)$$

Where: Erw = Open water evaporation

ET₀ = Penman Monteith reference evapotranspiration

kw = correction factor for open water evaporation (0.7)

To determine the amount of volume of water lost in a particular year, submergence curves were used and sixty percent of the maximum water spread area of that year was multiplied with average open water evaporation data.

There are no studies available for seepage from reservoirs. The Central ground Water Board recommends recharge from storage tanks and ponds as 1.4 mm per day for the period in which the tank has water, based on the average area of water spread. If data on the average area of water spread is not available, then the Board recommends that 60 percent of the maximum water spread area may be used instead of average area of the water spread (Anonymous,1987) The average value of 1.429 m is taken as evaporation loss from the reservoir and seepage is taken as 0.511 m per year(Annexure A3). The average total losses are therefore 1.940 m per year. The total losses are calculated on the basis of maximum water available for a particular year using the following relation:

$$\text{Percentage Losses} = \frac{\text{Maximum water spread in m}^2 \text{ at maximum capacity}}{\text{Maximum capacity in m}^3} \times (0.6) \times (1.940) \times 100 \dots\dots\dots(3.2)$$

3.13. Reservoir Inflow and Outflow(Water Balance) :

The gauge details of the reservoirs were used for determining the inflow and outflow from reservoirs .The difference of gauge data prior to monsoon (minimum level attained i.e S_{t min}) and at the end of the monsoon(maximum gauge attained i.e S_{t max}) gives the quantity of

inflow in the reservoirs. Similarly the difference of the maximum gauge of the previous year monsoon($S_{t \max}$) and minimum gauge of next year($S_{t+1 \min}$) gives the total outflow from the reservoir. To determine the release, the average reservoir evaporation and seepage losses are deducted from the total outflow for that year. Since average losses are deducted, some drought years may show negative releases. Such negative releases are rounded off to zero.

$$Q_t = S_{t \max} - S_{t \min} \dots\dots\dots (3.3)$$

$$OF_t = S_{t \max} - S_{t+1 \min} \dots\dots\dots (3.4)$$

3.14 Reservoir Operations

3.14.1. Reservoir system analysis model

Reservoir system analysis models are used for various purposes in variety of settings. Models are used in planning studies to help in the formulation and evaluation of alternative plans for water related problems ,needs allocations etc. Feasibility studies may involve proposed construction projects as well as reallocations of storage capacity and most importantly, to develop or reevaluate operating policies for existing reservoir systems. Execution of models during actual reservoir operations, in support of real-time release decisions, is another major area of application. In brief, reservoir system management practices and associated modeling and analysis methods involve allocating storage capacity and stream flow between multiple uses and users; minimizing the risks and consequences of water shortages and flooding; optimizing the beneficial use of water, energy, and land resources; and managing environmental resources.

3.14.2. Standard Operation Policy (SOP)

A reservoir operating policy is a sequence of release decisions in operational periods specified as a function of the state of the system. The state of the system in a period is generally defined by the reservoir storage at the beginning of a period (S_t) and the inflow to the reservoir during the period (Q_t). Once the operating policy is known, the reservoir operation can be simulated in time with a given inflow sequence. A number of optimization algorithms have been developed for deriving reservoir operating policies. However, the most common policy implemented in practice is the so-called Standard Operating Policy (SOP), which itself is not based on or derived from any optimization algorithm.(Vedula and Majumdar, 2005)

The standard operation policy (SOP) aims to best meet the demand in each period based on the water availability in that period. It thus uses no foresight on what is likely to be the scenario during the future periods in a year. The available water in any period is the sum of the storage S_t at the beginning of the period, and the inflow Q_t during the period.

The release made as per the standard operating policy is not necessarily optimum as no optimization criterion is used in the release decisions. For highly stressed systems, the standard operating policy performs poorly in terms of distributing the deficits across the periods in a year.

With evaporation and seepage losses included, the standard operating policy may be expressed as

$$R_t = S_t + Q_t - L_t - S_{t+1} \text{ minc} \dots \dots \dots (3.5)$$

$$S_{t+1} = S_t \text{ minc} \dots \dots \dots (3.6)$$

S_t is the storage at the beginning of the period. Q_t is the inflow during the period t , L_t is the evaporation and seepage losses during the period t , R_t is the release during the period t , and S_{t+1} is minimum conservation pool level.

To prepare the Standard Operation Policy for reservoirs of Upper Berach Basin, the minimum conservation pool levels were taken between 10 percent (Bennet, 1977) to 25 percent of total storage and tested on Linear Interactive Discrete Optimizer (LINDO 6.1 Release) software. The maximum value of conservation pool level at which the software gives feasible solution is taken as minimum feasible conservation pool level.

3.14.3. Formulation of Optimization Model

Optimization models are formulated in terms of determining values for a set of decision variables which will maximize or minimize an objective function subject to constraints. The objective function and constraints are represented by mathematical expressions as a function of the decision variables. For a reservoir operation problem, the decision variables are typically release rates and end-of-period storage volumes. Constraints typically includes minimum and maximum storage capacities.

Objectives and Objective Functions. - The objective function is the heart of an optimization model. The objective function, which is to be minimized or maximized subject to constraints, must be expressed in the proper mathematical format as a function of the

decision variables. For example, in linear programming, the solution algorithm finds values for the n decision variables (X_j) which minimize the linear objective function (Z):

$$Z = c_1X_1 + c_2X_2 + c_3X_3 + \dots + c_nX_n \dots \dots \dots (3.7)$$

$$j = 1, 2, 3, \dots \dots \dots n$$

where the c_j are constraints.

Optimization models, includes a diverse set of techniques or algorithms. The type of solution procedure (or algorithm) most appropriate for any particular constrained optimization model depends on the particular mathematical form of the objective function and of the constraint equations. Most applications to water resources systems analysis involve linear programming (LP) and dynamic programming (DP). Optimization models are formulated in terms of determining values for a set of decision variables that will maximize or minimize an objective function subject to constraints. If the objective function, as well as the constraints, are linear, then a very efficient procedure called “linear programming,” (LP) may be used. The LP has been one of the most widely used techniques in water resources because unlike most other optimization techniques, LP software packages are available and user friendly. Though there are some limitations to the use of LP in a deterministic environment, numerous water resources studies have utilized it along with additional techniques for a wide variety of problems. The LP has also been extensively used in stochastic reservoir system modeling as a main technique within different approaches such as chance constrained LP, stochastic LP for Markov process, and stochastic programming with recourse and reliability programming.

Given a reservoir of known capacity, K , and a sequence of inflows, the reservoir operation problem involves determining the sequence of release R_t that optimizes an objective function.

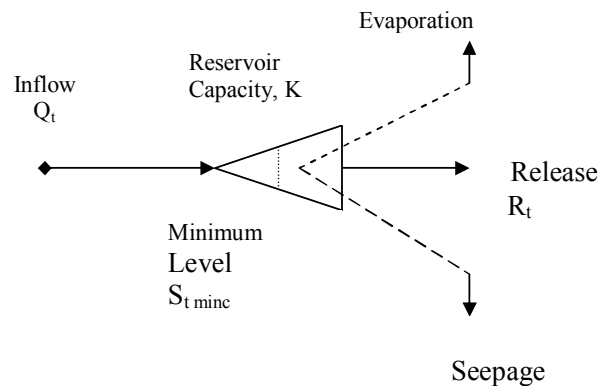


Fig.3.8 : Schematic Diagram of Optimization Model

Considering the simplest objective of maximizing the release to the best extent possible with the constraint to maintain the reservoir at minimum feasible conservation pool level.($S_{t\min}$) at all times. This can be formulated as a steady state LP problem as follows.

$$\text{Max } \sum R_t \dots\dots\dots (3.8)$$

subject to

$$S_{t+1} = S_t + Q_t - L_t - R_t$$

$$R_t \geq 0$$

$$S_t \geq S_{t\min}$$

For feasible optimum sustained release(f_{sr}), the extra constraint included is

$$R_t \geq R_{f_{sr}}$$

The 38 years release values (R_t) for the above maximization equation are taken from standard operation policy releases of different reservoirs (Tables 4.8, 4.12, 4.16, 4.20, and 4.24). The $S_{t\min}$ constraints for Bada Madar, Badi, Fateh Sagar, Pichhola and Udai Sagar reservoirs and taken as 16 percent, 23 percent, 21.5 percent, 25 percent and 16 percent storages. Whereas the $R_{f_{sr}}$ values taken are 0.3 mcm, 2 mcm, 1.46 mcm, 2.19 mcm and 10 mcm for these reservoirs. The $S_{t\min}$ and $R_{f_{sr}}$ are those values at which processing software LINDO gives feasible solutions.

3.15. Reservoir Release Policies and Operation Rules.

A reservoir regulation plan, operating procedure, or release policy is a set of rules for determining the quantities of water to be stored and to be released or withdrawn from a reservoir, or from a system of several reservoirs under various conditions.

Reservoir operating procedures are used to guide operations when there are departures from ideal conditions. These operations guides include establishment of target storage levels and releases and/or diversions to be sought during times of need. Given the large number and variety of water use beneficiaries, it seems that ideal conditions seldom, if ever, occur. Thus, operating procedures are used at all times to obtain some mix of performance on various objectives' performance scales. It is typically during periods of drought that non-ideal conditions occur. Low storage and inflow supplies require that decisions be made in the short term for allocation of available supplies.

The number of methods are used to define target conditions and operating policies for non ideal conditions. The simplest type of rules are those that define each reservoir's target storage level for each season of a year. If the reservoir pool level is above the target or desired level, the release rate is increased. Conversely, if the reservoir pool level is below that desired, the release rate is decreased and shortages of deliveries are to be augmented from other sources.

To derive the eco-technological operating policies for reservoirs of upper Berach basin, the last 38 year's inflow data of the reservoirs are optimized and it is assumed that same hydrological process will be repeated in coming years. The various policies and rules are as follows:

1. **Fraction of Inflow and initial storage:** A fraction of the reservoir inflow and initial storage may be released as per standard operating policy(SOP)
2. **Fixed Sustained Release :-** A fixed ,sustained release may be given, irrespective of the inflow in the reservoirs. This will include both, the spells of droughts when no inflow occurs and good rainfall years when reservoirs spill over.
3. **Fixed Sustained Release with Augmentation:** The fixed sustained release may be further increased by incorporating the augmentations , if any ,from other river basins
4. **Maximized releases as per Linear Decision Rule :** This rule follows the Fraction of Inflow (FOI) Release rule. Flows are considered to be useful if they fall above a threshold which in this exercise is minimum conservation pool level . Linear decision rules are formed by optimizing the releases as obtained by the standard operation policy.

4. RESULTS AND DISCUSSION

This study has been undertaken with the objective to develop optimal operation plan for eco-technological management of selected surface reservoirs of Upper Berach basin, Udaipur. The Upper Berach basin and its important, interlinked surface reservoirs were delineated on general topographic sheets. The hydrological, limnological and ecological details of the reservoirs were compiled and analysed to assess the water balance of the reservoirs; and to frame the eco-technological operation plans. The deterministic LP model was formulated and processed using LINDO 6.2 release software to derive optimum allocations. The results obtained from this study are presented and discussed as per the objectives of the study.

4.1. Delineation of inter linked surface reservoirs of upper Berach basin

Upper Berach basin was delineated using general topographic sheets 45 H/9, 45H/10 & 45 H/11. Scale 1:50000. The reservoirs selected for study were Bada Madar, Badi, Pichhola, Fateh Sagar and Udai Sagar. These reservoirs are interconnected and overflow of one reservoir enters into another reservoir. They form world famous Udaipur Lake System. The selected reservoirs were delineated on the topographic sheets and their morphometric details were compiled which are presented in the Table 3.2. The surface area of reservoirs, measured from topographic sheets, represent water spread at full tank level (FTL), not at highest flood level (HFL). Therefore, in order to save and conserve the reservoirs, it is very necessary to recognize the importance of HFL and new peripheries of the reservoirs should be surveyed, marked on ground and all governmental records should be corrected accordingly.

The gross, live and dead storages data are based on some 50 years old survey. The siltation and encroachment in reservoirs have totally altered the depth and water spread of the reservoirs. Therefore, it is recommended that the capacities of all reservoirs should be reassessed using latest survey instruments in future.

4.2. Assessment of Reservoir's Water Storage and Utilization.

4.2.1. Analysis of Rainfall

The variation of rainfall in upper Berach basin is shown Fig 4.1. The average rainfall of the basin is 600.67 mm. The years 1973 and 2006 witnessed heavy rainfall and recorded 1272 mm and 917 mm rains respectively. The lowest rainfall 286 mm occurred in the year 1987. The Rainfall data of year 1970 to year 2007 were analyzed and classified in different categories as shown in Table 4.1 as per the classification given in Subramanyam, IMD and

Fig 4.1

Table 4.1

Walker criteria. The classification of rainfall data shows that every decade has alternate incidences of drought years as well as normal to good rainfall years. The decade 1971- 1980 has two large to severe drought years and two good rainfall years. The decade 1981-1990 had almost same phenomena. The situation was worst in this decade where there were five large to severe drought years and just one good rainfall year . There was continuous drought from 1997 to 2003. Years 2005 and 2006 witnessed good rainfalls, but the years 2007 and 2008 were again disappointing. The analysis reveals that the basin experiences alternate spells of drought and good rains. This underlines the importance and need of planned utilization of reservoir waters.

4.2. 2. Evaporation and Seepage Losses

The total evaporation and seepage losses in upper Berach basin are 1.940 m per year. The reservoir losses in terms of percent of their total capacity is shown in the Table 4.2. The reservoir Bada Madar has maximum 65 percent losses followed by Pichhola (40 percent), Fateh Sagar (25 percent), Udai Sagar (21 percent) and Badi (16 percent). The continuous silting and shallow water cover more surface area and hence increase the evaporation.

Table 4.2 : Evaporation and Seepage losses in percent of Capacity

S.No.	Reservoir	Max Water Spread Area	Max Capacity	Percent losses
1	Bada Madar	0.80 Sq. km	2.38 mcm	65
2	Badi	1.46 Sq. km	10.50 mcm	16
3	Fateh Sagar	2.59 Sq. km	12.09 mcm	25
4	Pichhola	4.60 Sq. km	13.676 mcm	40
5	Udai Sagar	5.60 Sq. km	31.149mcm	21

4.2.3 Reservoir's Inflow and Outflow and Storages

The actual inflow, minimum and maximum storage over the year and release for various reservoirs are given in Tables 4.3 to 4.7. The waste water inflow into the reservoirs (Lakes) and withdrawal from bed tube-wells are not included in making the assessment of inflows and releases. This is based on the assumption that in coming years all waste water entering into the lakes will be diverted and all lake bed tube-wells will be grouted.

The analysis of 38 years data shows that the Bada Madar reservoir overflowed 20 times and remained below 7 percent storage for 16 times . Normally it overflows at least once in 3 years but the situation was worst between 1998 to 2004 when there was no overflow and even lake got dried in the year 2001.

The Badi reservoir overflowed just 4 times in 38 years and no fixed occurrence schedule of overflow can be derived out with respect to the time period in years. The analysis of data reveals that the reservoir was almost dry in the years 2004 and 2005(pre monsoon). The reservoir received insignificant water in the years 1972(0.53mcm inflow),1982(0.50 mcm inflow),1987(0.55 mcm inflow),2000(zero mcm inflow),2002(0.58 mcm inflow)and 2004 (0.53 mcm inflow).

The Pichhola reservoir overflowed 16 times in 38 years with occurrence of overflows atleast once in 3 years but the situation was worst between 1986 to 1989 and 1997 to June 2005, when there was no overflow and the reservoir was at insignificant levels in the years 1973,1988 and 2002,2003,2004,2005.The reservoir was totally dry in the year 2005(pre monsoon). The reservoir did not receive sufficient water in the years 1972(0.1345 mcm inflow), 1987(0.05666mcm inflow) and 2004(0.3398 mcm inflow).

The Fateh Sagar reservoir overflowed 14 times in 38 years with occurrence of overflows atleast once in 3 years. The situation was worst between the years 1995 and 2005 June, During these years there was no overflow and even got dried in the year 2003 and 2005(pre monsoon). The reservoir did not receive sufficient water in the years 1972(0.3 mcm inflow), 1987 (zero mcm inflow),1999(zero mcm inflow),2000(zero mcm inflow) ,2002(zero mcm inflow) and 2004 (zero mcm inflow).

The Udai Sagar reservoir overflowed 6 times in 38 years with occurrence of overflows normally as once in 10 years. The reservoir attained insignificant levels in the years 1970,1973(June months) and 2000,2002,2003,2004,2005. The reservoir was totally dry in the year 2005(pre monsoon). The reservoir did not receive sufficient water in the years 1971 (0.56 mcm inflow), 1974 (0.56 mcm inflow), 1982 (0.53 mcm inflow), 1995(0.49mcm inflow) 1999(zero mcm inflow) 2000(zero mcm inflow) , 2003(0.19 mcm inflow). 2004(0.39 mcm inflow). The reservoir can safely accommodate 5.6 mcm water above its maximum gauge. The safe maximum storage was recorded in the year 2006 as 34.5592 mcm.

The spell from the year 1997 to 2005 (June) was the worst when there was continuous drought and the inflows to the reservoirs were meager. But, even then there were regular extraction of reservoir's surface and under ground waters, without any considerations for reservoir ecosystems. There is no pre determined schedule and policy for withdrawal and utilization of reservoir's storages and inflows.The water is even withdrawn deep below from the sill level. Therefore,the unplanned and excessive water withdrawal from surface reservoirs of upper Berach basin should be stopped. The withdrawals should be governed by reservoir operation policies with the aim to keep reservoirs always at conservation pool levels..

Table 4.3 : Inflow, Storages and Release Statement of Bada Madar Reservoir (in mcm)

S.N	Year	S_{tmin}	S_{tmax}	Q_t	OF_t	L_t	R_t	Remark
1	1970	0.8495	2.3957	1.5291	2.1974	1.5572	0.6403	Overflowed
2	1971	0.1982	2.5825	1.2658	2.4126	1.6787	0.7340	Overflowed
3	1972	0.1699	1.5291	1.3592	1.4102	0.9939	0.4163	
4	1973	0.1189	2.3787	2.2597	2.1167	1.5461	0.5706	Overflowed
5	1974	0.2619	1.5291	1.2389	1.3819	0.9939	0.3879	
6	1975	0.1473	2.0247	1.8774	1.7259	1.3161	0.4099	
7	1976	0.2987	2.3787	2.0799	2.1663	1.5461	0.6202	Overflowed
8	1977	0.2124	2.3787	2.1663	2.1804	1.5461	0.6343	Overflowed
9	1978	0.1982	2.3787	2.1813	1.6849	1.5461	0.1388	Overflowed
10	1979	0.6938	2.3787	1.6849	2.1521	1.5461	0.6060	Overflowed
11	1980	0.2265	1.4867	0.6938	1.3168	0.9663	0.3504	
12	1981	0.1699	2.3787	2.2088	2.0247	1.5461	0.4786	Overflowed
13	1982	0.3540	1.2488	0.8951	1.0902	0.8117	0.2785	
14	1983	0.1586	2.3787	2.2201	1.9638	1.5461	0.4177	Overflowed
15	1984	0.4148	2.3787	1.9638	2.2102	1.5461	0.6640	Overflowed
16	1985	0.1685	2.3787	2.2102	2.0601	1.5461	0.5140	Overflowed
17	1986	0.3186	2.2003	1.8817	2.0757	1.4302	0.6455	
18	1987	0.1246	1.1539	1.0293	0.9869	0.7501	0.2368	
19	1988	0.1671	2.3787	2.2116	2.0318	1.5461	0.4856	Overflowed
20	1989	0.3469	2.3787	2.0318	2.0813	1.5461	0.5352	Overflowed
21	1990	0.2973	2.3787	2.0813	2.0955	1.5461	0.5494	Overflowed
22	1991	0.2832	1.8576	1.5744	1.6877	1.2075	0.4803	
23	1992	0.1699	2.4022	2.2088	1.8571	1.5614	0.2956	
24	1993	0.5451	2.3787	1.8336	2.2088	1.5461	0.6626	Overflowed
25	1994	0.1699	2.3787	2.2088	2.2088	1.5461	0.6626	Overflowed
26	1995	0.1699	1.8010	1.6311	1.3989	1.1706	0.2282	
27	1996	0.4021	2.4070	2.0049	2.0955	1.5645	0.5310	Overflowed
28	1997	0.3115	2.3787	2.0672	1.9822	1.5461	0.4361	Overflowed
29	1998	0.3964	1.4159	1.0194	1.1185	0.9203	0.1982	
30	1999	0.2973	0.9175	0.6202	0.7476	0.5964	0.1512	
31	2000	0.1699	0.8042	0.6343	0.8042	0.5227	0.2815	
32	2001	0.0000	2.0955	2.0955	1.9256	1.3621	0.5635	
33	2002	0.1699	0.8948	0.7249	0.7249	0.5816	0.1433	
34	2003	0.1699	2.2654	2.0955	2.0955	1.4725	0.6230	
35	2004	0.1699	1.5376	1.3677	1.3677	0.9995	0.3683	
36	2005	0.1699	2.4211	2.2512	1.9511	1.5737	0.3773	Overflowed
37	2006	0.4701	2.4070	1.9369	2.1748	1.5645	0.6102	Overflowed
38	2007	0.2322	1.7274	1.4952	1.7274	1.1228	0.6046	

Table 4.4 : Inflow, Storages and Release Statement of Badi Reservoir (in mcm)

Year	S _{tmin}	S _{tmax}	Q _t	OF _t	L _t	R _t	Remark
1970	2.4183	7.1077	4.6894	3.3698	1.1500	5.9576	
1971	3.7379	6.1732	2.4353	3.3882	0.9988	5.1744	
1972	2.7850	3.3216	0.5366	0.9670	0.5374	2.7842	
1973	2.3546	10.3358	7.9813	4.1457	1.6723	8.6635	Overflowed
1974	6.1902	6.9802	0.7901	3.6501	1.1294	5.8508	
1975	3.3301	7.9430	4.6129	3.3188	1.2852	6.6578	
1976	4.6242	8.4103	3.7860	5.0122	1.3608	7.0495	
1977	3.3981	7.1926	3.7945	2.1238	1.1638	6.0289	
1978	5.0688	8.6651	3.5963	3.1857	1.4020	7.2631	
1979	5.4794	7.6599	2.1804	3.7039	1.2394	6.4205	
1980	3.9559	5.9608	2.0049	2.5627	0.9645	4.9964	
1981	3.3981	6.0033	2.6052	2.4778	0.9713	5.0320	
1982	3.5255	4.0352	0.5097	0.9486	0.6529	3.3823	
1983	3.0866	8.5094	5.4228	3.7379	1.3768	7.1326	
1984	4.7715	6.6263	1.8548	3.4151	1.0721	5.5541	
1985	3.2112	6.4280	3.2169	3.0866	1.0401	5.3880	
1986	3.3415	4.4798	1.1384	0.6428	0.7248	3.7550	
1987	3.8370	4.3892	0.5522	2.8218	0.7102	3.6790	
1988	1.5674	2.9096	1.3422	0.4913	0.4708	2.4388	
1989	2.4183	6.7537	4.3354	2.0105	1.0927	5.6609	
1990	4.7432	10.3358	5.5927	3.1432	1.6723	8.6635	Overflowed
1991	7.1926	8.4952	1.3026	3.6813	1.3745	7.1207	
1992	4.8140	10.3358	5.5219	3.4972	1.6723	8.6635	
1993	6.8386	8.4103	1.5716	3.9106	1.3608	7.0495	
1994	4.4996	10.3358	5.8362	3.7096	1.6723	8.6635	Overflowed
1995	6.6263	7.4192	0.7929	3.2452	1.2004	6.2187	
1996	4.1740	5.9948	1.8208	2.9224	0.9700	5.0248	
1997	3.0724	4.0466	0.9741	0.8348	0.6547	3.3918	
1998	3.2118	4.0664	0.8546	1.0931	0.6579	3.4084	
1999	2.9733	3.5680	0.5947	2.2654	0.5773	2.9907	
2000	1.3026	0.8778	0.0000	0.1416	0.1420	0.7358	
2001	0.7363	1.7783	1.0421	1.3451	0.2877	1.4906	
2002	0.4333	1.0194	0.5862	0.6740	0.1649	0.8545	
2003	0.3455	3.1257	2.7802	2.4177	0.5057	2.6199	
2004	0.7079	1.2460	0.5380	1.0477	0.2016	1.0444	
2005	0.1982	5.5700	5.3718	2.3707	0.9012	4.6688	
2006	3.1993	10.4987	7.2994	0.9274	1.6987	8.8000	Overflowed

Table 4.5 : Inflow, Storages and Release Statement of Fateh Sagar Reservoir (in mcm)

S.N	Year	$S_{t\min}$	$S_{t\max}$	Q_t	OF_t	L_t	R_t	Rt in mld	Remark
1	1970	2.6051	12.0913	9.4861	6.7323	3.0228	3.7095	10.1630	Overflowed
2	1971	5.3590	8.9481	3.5892	5.7200	2.2370	3.4830	9.5424	
3	1972	3.2281	3.5113	0.2832	2.0105	0.8778	1.1327	3.1032	
4	1973	1.5008	12.0913	10.5905	5.6005	3.0228	2.5777	7.0621	Overflowed
5	1974	6.4908	7.2718	0.7810	2.7722	1.8179	0.9543	2.6145	
6	1975	4.4995	12.0913	7.5917	5.3377	3.0228	2.3149	6.3422	Overflowed
7	1976	6.7536	12.0913	5.3377	5.5773	3.0228	2.5545	6.9985	Overflowed
8	1977	6.5140	12.1196	5.6056	6.3430	3.0299	3.3131	9.0769	Overflowed
9	1978	5.7766	12.0063	6.2297	6.0598	3.0016	3.0582	8.3787	Overflowed
10	1979	5.9465	11.4683	5.5218	6.0173	2.8671	3.1502	8.6308	
11	1980	5.4510	12.0913	6.6403	6.9376	3.0228	3.9148	10.7255	Overflowed
12	1981	5.1537	11.6099	6.4562	5.4510	2.9025	2.5485	6.9822	
13	1982	6.1589	7.1358	0.9769	3.7038	1.7840	1.9199	5.2599	
14	1983	3.4320	12.0913	8.6593	5.6350	3.0228	2.6122	7.1568	Overflowed
15	1984	6.4562	12.0913	5.6350	6.9801	3.0228	3.9573	10.8419	Overflowed
16	1985	5.1112	12.0913	6.9801	5.8616	3.0228	2.8388	7.7774	
17	1986	6.2297	8.9764	2.7467	5.2386	2.2441	2.9945	8.2041	
18	1987	3.7378	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
19	1988	0.4248	4.0776	3.6529	1.0477	1.0194	0.0283	0.0776	
20	1989	3.0299	12.0913	9.0614	5.2669	3.0228	2.2441	6.1482	Overflowed
21	1990	6.8244	12.0913	5.2669	5.1253	3.0228	2.1025	5.7603	Overflowed
22	1991	6.9659	11.2701	4.3042	5.8545	2.8175	3.0370	8.3205	
23	1992	5.4156	12.0913	6.6757	5.2528	3.0228	2.2299	6.1095	
24	1993	6.8385	11.3834	4.5448	6.3203	2.8458	3.4745	9.5191	
25	1994	5.0630	12.0913	7.0282	5.2952	3.0228	2.2724	6.2258	Overflowed
26	1995	6.7960	9.3446	2.5485	4.1286	2.3361	1.7925	4.9108	
27	1996	5.2160	6.9943	1.7783	2.5202	1.7486	0.7716	2.1141	
28	1997	4.4741	11.0889	6.6148	6.3883	2.7722	3.6161	9.9070	
29	1998	4.7006	8.9198	4.2192	3.7803	2.2299	1.5503	4.2475	
30	1999	5.1395	4.7204	0.0000	1.4357	1.1801	0.2556	0.7002	
31	2000	3.2848	2.4494	0.0000	1.0406	0.6124	0.4283	1.1734	
32	2001	1.4088	3.1913	1.7825	1.8440	0.7978	1.0462	2.8662	
33	2002	1.3473	0.9231	0.0000	0.9231	0.2308	0.6923	1.8968	
34	2003	0.0000	3.3980	3.3980	2.0388	0.8495	1.1893	3.2584	
35	2004	1.3592	1.2601	0.0000	1.2601	0.3150	0.9451	2.5892	
36	2005	0.0000	12.9691	12.9691	6.5695	3.2423	3.3272	9.1157	Overflowed
37	2006	6.3996	12.0913	5.6917	6.0881	3.0228	3.0653	8.3981	Overflowed

Note : The reservoir can safely accommodate 1.5 mcm water above FTL, which is its HFL
Maximum 14.91 mcm stored in the year 2005

Table 4.6 : Inflow, Storages and Release Statement of Pichhola Reservoir (in mcm)

S. No.	Year	S _{tmin}	S _{tmax}	Q _t	OF _t	L _t	R _t	R _t in mld	Remark
1	1970	3.5396	13.6770	10.1374	6.9376	5.4708	1.4668	4.0187	Overflowed
2	1971	6.7394	12.0559	5.3165	9.6065	4.8224	4.7841	13.1072	
3	1972	2.4494	2.5839	0.1345	1.0265	1.0336	0.0000	0.0000	
4	1973	1.5574	13.6770	12.1196	6.9376	5.4708	1.4668	4.0187	Overflowed
5	1974	6.7394	7.9924	1.2530	3.7166	3.1970	0.5196	1.4236	
6	1975	4.2758	13.6770	9.4012	6.6545	5.4708	1.1836	3.2429	Overflowed
7	1976	7.0226	12.2612	5.2386	4.8988	4.9045	0.0000	0.0000	
8	1977	7.3624	13.6770	6.3147	7.9429	5.4708	2.4721	6.7728	Overflowed
9	1978	5.7342	13.6770	7.9429	7.4756	5.4708	2.0048	5.4927	Overflowed
10	1979	6.2014	10.1091	3.9077	5.2245	4.0436	1.1808	3.2351	
11	1980	4.8847	13.6770	8.7924	9.2879	5.4708	3.8171	10.4578	Overflowed
12	1981	4.3891	13.2041	8.8150	7.7815	5.2817	2.4998	6.8488	
13	1982	5.4227	8.2119	2.7892	4.4457	3.2848	1.1610	3.1808	
14	1983	3.7661	13.6770	9.9109	6.2580	5.4708	0.7872	2.1567	Overflowed
15	1984	7.4190	13.6770	6.2580	8.7216	5.4708	3.2508	8.9062	Overflowed
16	1985	4.9554	13.6770	8.7216	7.1642	5.4708	1.6933	4.6393	Overflowed
17	1986	6.5129	10.1374	3.6246	5.5784	4.0550	1.5234	4.1738	
18	1987	4.5590	4.6156	0.0566	4.6015	1.8463	2.7552	7.5486	
19	1988	0.0142	9.9817	9.9675	5.4510	3.9927	1.4583	3.9954	
20	1989	4.5307	13.6770	9.1463	7.5323	5.4708	2.0615	5.6478	
21	1990	6.1447	13.6770	7.5323	6.7960	5.4708	1.3252	3.6308	Overflowed
22	1991	6.8810	13.6770	6.7960	9.8543	5.4708	4.3834	12.0094	Overflowed
23	1992	3.8228	13.6770	9.8543	7.2491	5.4708	1.7783	4.8720	Overflowed
24	1993	6.4279	13.2058	6.7779	9.4397	5.2823	4.1574	11.3900	
25	1994	3.7661	13.6770	9.9109	6.5270	5.4708	1.0562	2.8937	Overflowed
26	1995	7.1500	11.6099	4.4599	8.8348	4.6440	4.1909	11.4819	
27	1996	2.7750	13.6770	10.9020	8.0929	5.4708	2.6221	7.1839	Overflowed
28	1997	5.5841	12.7029	7.1188	7.5351	5.0812	2.4539	6.7231	
29	1998	5.1678	10.6188	5.4510	5.9465	4.2475	1.6990	4.6548	
30	1999	4.6723	7.2774	2.6051	4.2475	2.9110	1.3366	3.6618	
31	2000	3.0299	5.1253	2.0954	3.7661	2.0501	1.7160	4.7014	
32	2001	1.3592	5.9182	4.5590	4.8705	2.3673	2.5032	6.8581	
33	2002	1.0477	6.9376	5.8899	5.5501	2.7750	2.7750	7.6029	
34	2003	1.3875	7.0509	5.6634	6.2580	2.8204	3.4377	9.4183	
35	2004	0.7929	1.1327	0.3398	1.1327	0.4531	0.6796	1.8619	
36	2005	0.0000	14.8380	14.8380	7.3057	5.9352	1.3705	3.7549	Overflowed
37	2006	7.5323	13.6770	6.1447	6.8530	5.4708	1.3822	3.7869	Overflowed

Note: Pichhola can safely accommodate 4 mcm water above FTL, which is its HFL

Table 4.7 : Inflow, Storages and Release Statement of Udai Sagar Reservoir (in mcm)

Year	S _{tmin}	S _{tmax}	Q _t	OF _t	L _t	R _t	IRR _t	IND _t	Remark
1970	1.7727	22.0876	20.3149	16.1409	4.6384	11.5025	11.0424	0.4602	
1971	5.9467	6.5130	0.5663	4.2688	1.3677	2.9011	1.4803	1.4208	
1972	2.2442	3.5538	1.3097	2.0020	0.7463	1.2557	0.4451	0.8106	
1973	1.5518	31.1491	29.5973	22.9158	6.5413	16.3745	15.9193	0.4552	overflowed
1974	8.2333	8.7784	0.5451	5.1962	1.8435	3.3528	2.5273	0.8255	
1975	3.5821	29.7333	26.1511	23.2769	6.2440	17.0329	16.3575	0.6754	
1976	6.4564	29.7333	23.2769	22.9937	6.2440	16.7497	15.9243	0.8255	
1977	6.7395	25.0892	18.2081	21.4221	5.2687	16.1534	14.9272	1.2261	
1978	3.6671	31.1491	27.4820	23.6450	6.5413	17.1037	16.0786	1.0251	overflowed
1979	7.5041	9.3801	1.8760	6.0528	1.9698	4.0830	2.6572	1.4258	
1980	3.3273	5.3803	1.8406	2.8317	1.1299	1.7019	0.6357	1.0661	
1981	2.5486	6.9661	4.4175	4.1343	1.4629	2.6715	1.3356	1.3359	
1982	2.8317	3.3698	0.5380	2.0757	0.7077	1.3680	0.3925	0.9755	
1983	1.2941	31.1491	29.8550	27.6094	6.5413	21.0681	20.3425	0.7256	overflowed
1984	3.5397	14.1587	10.6190	11.2562	2.9733	8.2828	7.1218	1.1610	
1985	2.9025	13.5923	10.6615	10.3698	2.8544	7.5154	5.6337	1.8817	
1986	3.2225	3.6529	0.4304	2.3928	0.7671	1.6257	0.4350	1.1907	
1987	1.2601	2.2229	0.9628	0.5239	0.4668	0.0571	0.0571	0.0000	
1988	1.6990	3.5397	1.8406	2.4070	0.7433	1.6636	1.6636	0.0000	
1989	1.1327	18.3780	17.2453	14.8100	3.8594	10.9506	9.7096	1.2410	
1990	3.5680	29.5350	25.9670	25.3582	6.2024	19.1559	17.4696	1.6863	
1991	4.1768	8.4952	4.3184	6.0174	1.7840	4.2334	2.6774	1.5560	
1992	2.4778	32.5650	28.6713	27.7510	6.8386	20.9124	19.3110	1.6013	overflowed
1993	4.8140	8.1696	3.6388	5.4228	1.7156	3.7072	2.1511	1.5560	
1994	2.7468	31.1491	28.4023	25.2449	6.5413	18.7036	17.1476	1.5560	overflowed
1995	5.9042	6.4847	0.4956	4.1060	1.3618	2.7442	0.9178	1.8265	
1996	2.3787	6.6829	4.3042	6.1873	1.4034	4.7839	3.1337	1.6502	
1997	0.4956	6.2298	2.9025	3.4406	1.3083	2.1323	0.3214	1.8109	
1998	2.7893	4.8423	2.0530	2.3645	1.0169	1.3476	0.0000	1.3476	
1999	2.4778	2.4778	0.0000	1.2601	0.5203	0.7398	0.0000	0.7398	
2000	1.2176	1.6877	0.4701	0.5550	0.3544	0.2006	0.0000	0.2006	
2001	1.1327	3.3061	2.1734	2.0119	0.6943	1.3177	0.0972	1.2205	
2002	1.2941	1.2941	0.0000	0.1614	0.2718	0.0000	0.0000	0.0000	
2003	1.1327	1.3253	0.1926	0.1926	0.2783	0.0000	0.0000	0.0000	
2004	1.1327	1.5291	0.3964	1.5291	0.3211	1.2080	0.9029	0.3051	
2005	0.0000	24.7777	24.7777	19.6098	5.2033	14.4065	12.5248	1.8817	
2006	5.1679	34.5591	29.3912	31.1491	7.2574	23.8917	Data NA	1.8817	overflowed

4.3. Development of optimal operation plans and recommendations for eco technological management of selected reservoirs .

Reservoir Operation Policies are prepared considering four criterias. To start with Standard Operation Policies(SOP) are prepared using simple arithmetics. The inflow and reservoir losses along with feasible conservation pool level data were used to estimate optimum releases using LINDO 6.1 release software.

4.3.1. Reservoir Operation Policies for Bada Madar Reservoir

To derive the reservoir operation policy for Bada Madar reservoir, The actual end of year storage values ($S_{t \min}$) and end of monsoon storage value ($S_{t \max}$) are taken as per the data provided by the Water Resources Department. Using these data the inflow and outflow quantities were determined. To start with SOP (Table 4.8) was prepared and three scenario were analyzed :- (i) Releases as per SOP (ii) Releases as per sustained rate (Optimized) (iii) Maximum releases (Optimized).

The LINDO package gives feasible solution at 16 percent storage; therefore, standard operation policy (SOP) was prepared at this feasible conservation pool taking the actual inflow data. The releases were maximized using LINDO package and further, the sustained maximized fix release was determined by this software package. The comparison of minimum storages obtained by SOP, maximum release optimization and maximum sustained release optimization with actual storage and releases are shown in Tables 4.9 to 4.10 and Fig.4.2 & 4.3. While in SOP the minimum storages are at constant level of 16 percent, the values even go above this targeted level in maximum release optimization. There are few years when inflow is very very less, no supply can be made. The sustained release optimization keeps the reservoir between 16 percent to 38 percent with 20 percent storage for most of the times. The LINDO software gives maximum feasible sustained release of 0.3 mcm. With this sustained release of 0.3 mcm water, there will be ensured drinking water availability to the farmers and villagers for 85 percent of times ; as well as enough ground water availability for irrigation. The sustained supply can provide ensured irrigation to atleast 20 hectare land at 40 percent irrigation efficiency.

The Linear Decision Rule is prepared using the inflow data and optimized maximum releases (Table 4.11 & Fig 4.4). The linear regression analysis gives the value of R^2 as 0.7969. The LDR for Madar Bada is

$$R_t = 0.3274Q_t - 0.2233 \dots \dots \dots (4.1)$$

This means that no release should be made if inflow is less then 0.68 mcm, but in that case, maintained conservation pool level of 0.38 mcm will sustainably augment minimum 6.54 ham ground water . This will help in ensuring ground water supply for drinking and irrigation even in no inflow drought years.

Table 4.8 : Standard Operation Policy for Bada Madar Reservoir (in mcm)

Year	S _t	Q _t	S _t +Q _t	L _t	Net Available	S _{t+1}	R _t
1970	0.849521	1.529139	2.37866	1.546129	0.832531	0.38	0.452531
1971	0.38	1.265787	1.645787	1.069762	0.576025	0.38	0.196025
1972	0.38	1.359234	1.739234	1.130502	0.608732	0.38	0.228732
1973	0.38	2.259727	2.639727	1.715823	0.923904	0.38	0.543904
1974	0.38	1.238885	1.618885	1.052276	0.56661	0.38	0.18661
1975	0.38	1.877442	2.257442	1.467338	0.790105	0.38	0.410105
1976	0.38	2.079912	2.459912	1.598943	0.860969	0.38	0.480969
1977	0.38	2.16628	2.54628	1.655082	0.891198	0.38	0.511198
1978	0.38	2.181288	2.561288	1.664837	0.896451	0.38	0.516451
1979	0.38	1.684884	2.064884	1.342175	0.722709	0.38	0.342709
1980	0.38	0.693776	1.073776	0.697954	0.375822	0.38	0
1981	0.38	2.208756	2.588756	1.682691	0.906065	0.38	0.526065
1982	0.38	0.895112	1.275112	0.828823	0.446289	0.38	0.066289
1983	0.38	2.220083	2.600083	1.690054	0.910029	0.38	0.530029
1984	0.38	1.96381	2.34381	1.523477	0.820334	0.38	0.440334
1985	0.38	2.210172	2.590172	1.683612	0.90656	0.38	0.52656
1986	0.38	1.88169	2.26169	1.470098	0.791591	0.38	0.411591
1987	0.38	1.029337	1.409337	0.916069	0.493268	0.38	0.113268
1988	0.38	2.211587	2.591587	1.684532	0.907056	0.38	0.527056
1989	0.38	2.031772	2.411772	1.567652	0.84412	0.38	0.46412
1990	0.38	2.081328	2.461328	1.599863	0.861465	0.38	0.481465
1991	0.38	1.574446	1.954446	1.27039	0.684056	0.38	0.304056
1992	0.38	2.208756	2.588756	1.682691	0.906065	0.38	0.526065
1993	0.38	1.83355	2.21355	1.438808	0.774743	0.38	0.394743
1994	0.38	2.208756	2.588756	1.682691	0.906065	0.38	0.526065
1995	0.38	1.631081	2.011081	1.307203	0.703878	0.38	0.323878
1996	0.38	2.004871	2.384871	1.550166	0.834705	0.38	0.454705
1997	0.38	2.067169	2.447169	1.59066	0.856509	0.38	0.476509
1998	0.38	1.019426	1.399426	0.909627	0.489799	0.38	0.109799
1999	0.38	0.620151	1.000151	0.650098	0.350053	0.38	0
2000	0.38	0.634309	1.014309	0.659301	0.355008	0.38	0
2001	0.38	2.095486	2.475486	1.609066	0.86642	0.38	0.48642
2002	0.38	0.724925	1.104925	0.718201	0.386724	0.38	0.006724
2003	0.38	2.095486	2.475486	1.609066	0.86642	0.38	0.48642
2004	0.38	1.36773	1.74773	1.136024	0.611705	0.38	0.231705
2005	0.38	2.251232	2.631232	1.710301	0.920931	0.38	0.540931
2006	0.38	1.936909	2.316909	1.505991	0.810918	0.38	0.430918
2007	0.38	1.495158	1.875158	1.218853	0.656305	0.38	0.276305

Note : Transfer to Fateh Sagar above 16'(1.415 mcm)

3.2' level will be maintained at 16 percent conservation level.

Table 4.9 : Comparative Storages for Bada Madar Reservoir (in mcm)

Year	SOP storages	Storages at Max Release(opt)	Storages at Sustained Release(opt)	Actual Storages
1970	0.8495	0.8495	0.8495	0.8495
1971	0.3800	0.3800	0.5373	0.1982
1972	0.3800	0.3800	0.3800	0.1699
1973	0.3800	0.3800	0.3800	0.1189
1974	0.3800	0.3800	0.6230	0.2619
1975	0.3800	0.3800	0.3800	0.1473
1976	0.3800	0.3800	0.4930	0.2987
1977	0.3800	0.3800	0.6026	0.2124
1978	0.3800	0.3800	0.6709	0.1982
1979	0.3800	0.3800	0.6948	0.6938
1980	0.3800	0.4000	0.5332	0.2265
1981	0.3800	0.3800	0.3800	0.1699
1982	0.3800	0.3800	0.6030	0.3540
1983	0.3800	0.3800	0.3800	0.1586
1984	0.3800	0.3800	0.6130	0.4148
1985	0.3800	0.3800	0.6046	0.1685
1986	0.3800	0.3800	0.6816	0.3186
1987	0.3800	0.3800	0.5986	0.1246
1988	0.3800	0.3800	0.3800	0.1671
1989	0.3800	0.3800	0.6030	0.3469
1990	0.3800	0.3800	0.6211	0.2973
1991	0.3800	0.3800	0.6474	0.2832
1992	0.3800	0.3800	0.4766	0.1699
1993	0.3800	0.3800	0.6368	0.5451
1994	0.3800	0.3800	0.5629	0.1699
1995	0.3800	0.3800	0.6670	0.1699
1996	0.3800	0.3800	0.5035	0.4021
1997	0.3800	0.5351	0.5762	0.3115
1998	0.3800	0.9073	0.9073	0.3964
1999	0.3800	0.6776	0.6776	0.2973
2000	0.3800	0.4571	0.4571	0.1699
2001	0.3800	0.3800	0.3800	0.0000
2002	0.3800	0.3800	0.5630	0.1699
2003	0.3800	0.3800	0.3800	0.1699
2004	0.3800	0.3800	0.5630	0.1699
2005	0.3800	0.3800	0.3800	0.1699
2006	0.3800	0.3800	0.6230	0.4701
2007	0.3800	0.3800	0.5980	0.2322

Fig. 4.2

Table 4.10 : Comparative Releases for Bada Madar Reservoir (in mcm)

Year	SOP Releases	Max Release(opt)	Sustained Release(opt)	Actual Releases
1970	0.4525	0.4573	0.3000	0.6403
1971	0.1960	0.1930	0.2480	0.7340
1972	0.2287	0.2330	0.2330	0.4163
1973	0.5439	0.5430	0.3000	0.5706
1974	0.1866	0.1830	0.2680	0.3879
1975	0.4101	0.4130	0.3000	0.4099
1976	0.4810	0.4830	0.3000	0.6202
1977	0.5112	0.5130	0.3000	0.6343
1978	0.5165	0.5130	0.3000	0.1388
1979	0.3427	0.3230	0.3000	0.6060
1980	0.0000	0.0000	0.0467	0.3504
1981	0.5261	0.5230	0.3000	0.4786
1982	0.0663	0.0630	0.3000	0.2785
1983	0.5300	0.5330	0.3000	0.4177
1984	0.4403	0.4430	0.3000	0.6640
1985	0.5266	0.5230	0.3000	0.5140
1986	0.4116	0.4130	0.3000	0.6455
1987	0.1133	0.1130	0.1895	0.2368
1988	0.5271	0.5230	0.3000	0.4856
1989	0.4641	0.4630	0.3000	0.5352
1990	0.4815	0.4830	0.3000	0.5494
1991	0.3041	0.3030	0.3000	0.4803
1992	0.5261	0.5230	0.3000	0.2956
1993	0.3947	0.3930	0.3000	0.6626
1994	0.5261	0.5230	0.3000	0.6626
1995	0.3239	0.3230	0.3000	0.2282
1996	0.4547	0.2980	0.3000	0.5310
1997	0.4765	0.0000	0.0144	0.4361
1998	0.1098	0.0000	0.0000	0.1982
1999	0.0000	0.0000	0.0000	0.1512
2000	0.0000	0.0000	0.0000	0.2815
2001	0.4864	0.4830	0.3000	0.5635
2002	0.0067	0.0030	0.3000	0.1433
2003	0.4864	0.4830	0.3000	0.6230
2004	0.2317	0.2330	0.2975	0.3683
2005	0.5409	0.5430	0.3000	0.3773
2006	0.4309	0.4330	0.3000	0.6102

Fig. 4.3

Table 4.11 : Inflow v/s Maximum Release (Optimized) for Bada Madar Reservoir (LDR Data in mcm)

Q_t	R_t
1.5291	0.4573
1.2658	0.1930
1.3592	0.2330
2.2597	0.5430
1.2389	0.1830
1.8774	0.4130
2.0799	0.4830
2.1663	0.5130
2.1813	0.5130
1.6849	0.3230
0.6938	0.0000
2.2088	0.5230
0.8951	0.0630
2.2201	0.5330
1.9638	0.4430
2.2102	0.5230
1.8817	0.4130
1.0293	0.1130
2.2116	0.5230
2.0318	0.4630
2.0813	0.4830
1.5744	0.3030
2.2088	0.5230
1.8336	0.3930
2.2088	0.5230
1.6311	0.3230
2.0049	0.2980
2.0672	0.0000
1.0194	0.0000
0.6202	0.0000
0.6343	0.0000
2.0955	0.4830
0.7249	0.0030
2.0955	0.4830
1.3677	0.2330
2.2512	0.5430
1.9369	0.4330

fig 4.4

4.3.2. Reservoir Operation Policies for Badi Reservoir

The LINDO package gives feasible solution at 23 percent(2.4 mcm) storage; therefore, SOP (Table 4.12) is prepared at this feasible conservation storage The inflow data obtained are used for preparing the SOP and determining the optimized maximum releases. The comparison of minimum storages obtained by SOP, Maximum release optimization and Maximum Sustained release optimization with actual storage and releases are shown in Tables 4.13 to 4.14 and Fig. 4.5 & 4.6. In SOP the minimum storages can be maintained at this level for 97 percent times.

The sustained release optimization keeps the reservoir between 23 percent to 100 percent with 34 percent storage i.e. above the sill level for most of the times. The sustained release obtained from optimization for Badi reservoir is 2 mcm which would be available for 65 percent times. In addition to this, there will be continuous recharging of ground water because of maintained good levels of water in the reservoir.

The Linear Decision Rule is prepared using the inflow data and optimized maximum releases (Table 4.15 & Fig. 4.7). The linear regression analysis gives the value of R^2 as 0.9976. The LDR for Badi reservoir is

$$R_t = 0.8384Q_t - 0.3929. \dots\dots\dots(4.2)$$

This means that no release should be made if inflow is less than 0.47 mcm(16.55 mcft)

Table 4.12 : Standard Operation Policy for Badi Reservoir (in mcm)

Year	S_t	Q_t	S_t+Q_t	L_t	Net Available	S_{t+1}	R_t
1970	2.4183	4.6894	7.1077	1.1500	5.9576	2.4000	3.5576
1971	2.4000	2.4551	4.8551	0.7856	4.0696	2.4000	1.6696
1972	2.4000	0.5423	2.9423	0.4761	2.4662	2.4000	0.0662
1973	2.4000	7.9713	10.3713	1.6781	8.6933	2.4000	6.2933
1974	2.4000	0.8070	3.2070	0.5189	2.6881	2.4000	0.2881
1975	2.4000	4.6299	7.0299	1.1374	5.8925	2.4000	3.4925
1976	2.4000	3.7860	6.1860	1.0009	5.1851	2.4000	2.7851
1977	2.4000	3.7945	6.1945	1.0023	5.1923	2.4000	2.7923
1978	2.4000	3.5963	5.9963	0.9702	5.0261	2.4000	2.6261
1979	2.4000	2.1804	4.5804	0.7411	3.8393	2.4000	1.4393
1980	2.4000	2.0049	4.4049	0.7127	3.6922	2.4000	1.2922
1981	2.4000	2.6052	5.0052	0.8098	4.1954	2.4000	1.7954
1982	2.4000	0.5097	2.9097	0.4708	2.4389	2.4000	0.0389
1983	2.4000	5.4228	7.8228	1.2657	6.5571	2.4000	4.1571
1984	2.4000	1.8548	4.2548	0.6884	3.5664	2.4000	1.1664
1985	2.4000	2.9337	5.3337	0.8630	4.4707	2.4000	2.0707
1986	2.4000	1.1384	3.5384	0.5725	2.9659	2.4000	0.5659
1987	2.4000	0.5522	2.9522	0.4777	2.4745	2.4000	0.0745
1988	2.4000	1.3422	3.7422	0.6055	3.1367	2.4000	0.7367
1989	2.4000	4.3354	6.7354	1.0898	5.6456	2.4000	3.2456
1990	2.4000	5.5927	7.9927	1.2932	6.6995	2.4000	4.2995
1991	2.4000	1.8689	4.2689	0.6907	3.5782	2.4000	1.1782
1992	2.4000	5.5219	7.9219	1.2818	6.6401	2.4000	4.2401
1993	2.4000	1.5716	3.9716	0.6426	3.3290	2.4000	0.9290
1994	2.4000	5.8362	8.2362	1.3326	6.9036	2.4000	4.5036
1995	2.4000	0.7929	3.1929	0.5166	2.6763	2.4000	0.2763
1996	2.4000	1.8208	4.2208	0.6829	3.5379	2.4000	1.1379
1997	2.4000	0.9741	3.3741	0.5459	2.8282	2.4000	0.4282
1998	2.4000	0.8546	3.2546	0.5266	2.7280	2.4000	0.3280
1999	2.4000	0.5947	2.9947	0.4845	2.5101	2.4000	0.1101
2000	2.4000	2.2654	4.6654	0.7549	3.9105	2.4000	1.5105
2001	2.4000	0.1416	2.5416	0.4112	2.1304	2.1304	0.0000
2002	2.1304	1.3451	3.4754	0.5623	2.9131	2.4000	0.5131
2003	2.4000	0.6740	3.0740	0.4974	2.5766	2.4000	0.1766
2004	2.4000	2.4177	4.8177	0.7795	4.0382	2.4000	1.6382
2005	2.4000	1.0477	3.4477	0.5578	2.8899	2.4000	0.4899
2006	2.4000	2.3707	4.7707	0.7719	3.9988	2.4000	1.5988
2007	2.4000	0.9274	3.3274	0.5384	2.7890	2.4000	0.3890

Table 4.13 : Comparative Storages for Badi Reservoir (in mcm)

Year	SOP Storages	Opt storages (Max Rel)	Opt Storages (sust. Rel)	Actual Storages
1970	2.4183	2.4180	2.4183	2.4183
1971	2.4000	2.4000	3.9570	3.7379
1972	2.4000	2.4000	3.3567	2.7850
1973	2.4000	2.4000	2.4000	2.3546
1974	2.4000	2.4000	6.7017	6.1902
1975	2.4000	2.4000	4.2773	3.3301
1976	2.4000	2.4000	5.4553	4.6242
1977	2.4000	2.4000	5.7426	3.3981
1978	2.4000	2.4000	5.9935	5.0688
1979	2.4000	2.4000	6.0337	5.4794
1980	2.4000	2.4000	4.8787	3.9559
1981	2.4000	2.4000	3.7767	3.3981
1982	2.4000	2.4000	3.3456	3.5255
1983	2.4000	2.4000	2.4000	3.0866
1984	2.4000	2.4000	4.5617	4.7715
1985	2.4000	2.4000	3.3736	3.2112
1986	2.4000	2.4000	3.5278	3.3415
1987	2.4000	2.4000	2.4000	3.8370
1988	2.4000	2.4000	2.4000	1.5674
1989	2.4000	2.4000	2.4000	2.4183
1990	2.4000	2.4000	3.6417	4.7432
1991	2.4000	2.4000	5.7425	7.1926
1992	2.4000	2.4000	3.9033	4.8140
1993	2.4000	2.4000	5.9018	6.8386
1994	2.4000	2.4000	4.2669	4.4996
1995	2.4000	2.4000	6.4665	6.6263
1996	2.4000	2.4000	4.0802	4.1740
1997	2.4000	2.4000	2.9500	3.0724
1998	2.4000	2.5047	2.5047	3.2118
1999	2.4000	2.8195	2.1895	2.9733
2000	2.4000	2.8633	2.8633	1.3026
2001	2.4000	2.4000	2.4000	0.7363
2002	2.3140	2.4000	2.4000	0.4333
2003	2.4000	2.4000	2.4000	0.3455
2004	2.4000	2.4000	2.4000	0.7079
2005	2.4000	2.4000	2.4000	0.1982
2006	2.4000	2.4000	2.4000	3.1993

fig. 4.5

Table 4.14 : Comparative Releases for Badi Reservoir (in mcm)

Year	SOP Releases	Max Release(opt)	Sustained Release(opt)	Actual Releases
1970	3.5576	3.5570	2.0000	5.9576
1971	1.6696	1.6517	2.0000	5.1744
1972	0.0662	0.0617	0.8636	2.7842
1973	6.2933	6.3017	2.0000	8.6635
1974	0.2881	0.2717	2.0000	5.8508
1975	3.4925	3.4817	2.0000	6.6578
1976	2.7851	2.7817	2.0000	7.0495
1977	2.7923	2.7917	2.0000	6.0289
1978	2.6261	2.6217	2.0000	7.2631
1979	1.4393	1.4417	2.0000	6.4205
1980	1.2922	1.2917	2.0000	4.9964
1981	1.7954	1.7917	2.0000	5.0320
1982	0.0389	0.0417	0.8343	3.3823
1983	4.1571	4.1617	2.0000	7.1326
1984	1.1664	1.1617	2.0000	5.5541
1985	2.0707	2.3117	2.0000	5.3880
1986	0.5659	0.5617	1.5070	3.7550
1987	0.0745	0.0717	0.0717	3.6790
1988	0.7367	0.7417	0.7417	2.4388
1989	3.2456	3.2417	2.0000	5.6609
1990	4.2995	4.3017	2.0000	8.6635
1991	1.1782	0.7017	2.0000	7.1207
1992	4.2401	4.2417	2.0000	8.6635
1993	0.9290	0.9317	2.0000	7.0495
1994	4.5036	4.5017	2.0000	8.6635
1995	0.2763	0.2717	2.0000	6.2187
1996	1.1379	1.1417	2.0000	5.0248
1997	0.4282	0.3269	0.7880	3.3918
1998	0.3280	0.0000	0.0000	3.4084
1999	0.1101	0.0000	0.0000	2.9907
2000	1.5105	0.0000	0.0000	0.7358
2001	0.0000	0.4817	0.4817	1.4906
2002	0.5131	0.1016	0.1017	0.8545
2003	0.1766	1.9417	1.9417	2.6199
2004	1.6382	0.0617	0.0617	1.0444
2005	0.4899	4.1117	2.0000	4.6688
2006	1.5988	5.7317	2.0000	8.8000

fig. 4.6

Table 4.15 : Inflow v/s Maximum Release (Optimized) for Badi Reservoir
(LDR Data in mcm)

Q_t	R_t
4.689358	3.557022
2.435295	1.65168
0.536614	0.06168
7.981254	6.30168
0.790055	0.27168
4.612901	3.481684
3.786034	2.78168
3.794529	2.79168
3.596307	2.62168
2.180438	1.44168
2.004871	1.29168
2.605199	1.79168
0.509713	0.04168
5.422779	4.16168
1.854788	1.16168
3.216855	2.31168
1.138359	0.56168
0.552189	0.07168
1.342244	0.74168
4.335391	3.24168
5.592683	4.30168
1.3026	0.70168
5.521889	4.24168
1.571615	0.93168
5.836212	4.50168
0.792887	0.27168
1.820808	1.14168
0.974118	0.326945
0.854619	0
0.594665	0
0	0
1.04208	0.48168
0.58617	0.101608
2.7802	1.94168
0.53803	0.06168
5.371807	4.11168
7.299371	5.73168

fig. 4.7.

4.3.3. Reservoir Operation Policies for Fateh Sagar Reservoir

The LINDO package gives feasible solution at 21.5 percent (2.6 mcm) storage; accordingly, SOP is prepared at this feasible conservation storage. The reservoir can safely accommodate 1.58 mcm water above its maximum gauge, (12.09 mcm) therefore an additional 1.58 mcm water should be stored additionally during overflow years. The safe maximum storage as recorded by Water Resources Department in the year 2005 is 14.91 mcm. The inflow data obtained were used for preparing the SOP (Table 4.16) and determining the optimized maximum releases. The comparison of minimum storages obtained by SOP, Maximum release optimization, Maximum Sustained release optimization and actual storages shown in Table 4.17 and Fig. 4.8. Similarly the comparative releases are shown in Table 4.18 & Fig. 4.9. In SOP, the minimum storages can not be maintained at 21.5 percent as they attain even 12 percent level and there are some years when inflow is very less, no supply can be made.

The sustained release optimization keeps the reservoir between 21.5 percent to 100 percent with 60 percent storage for most of the times. The sustained release obtained from optimization for Fateh Sagar reservoir is 1.46 mcm water i.e for 87 percent times, there will be ensured drinking water availability of 4 mld to the citizens of Udaipur. The good levels in the reservoirs will augment the ground water storages continuously.

The Linear Decision Rule (Table 4.19 & Fig.4.10) is prepared using the inflow data and optimized maximum releases. The linear regression analysis gives the value of R^2 as 0.8413. The LDR for Fateh Sagar is

$$R_t = 0.6826Q_t - 0.2192. \dots\dots\dots(4.3)$$

This means that no release should be made if inflow is less than 0.32 mcm(11.4 mcft)

Table 4.16 : Standard Operation Policy for Fateh Sagar Reservoir (in mcm)

Year	S_t	Q_t	S_t+Q_t	L_t	Net Available	S_{t+1}	R_t	Withdrawal in mld	Remark
1970	2.6051	9.4861	12.0913	3.0228	9.0685	2.6000	6.4685	17.7216	Overflow
1971	2.6000	3.5892	6.1892	1.5473	4.6419	2.6000	2.0419	5.5941	
1972	2.6000	0.3058	2.9058	0.7265	2.1794	2.1794	0.0000	0.0000	
1973	2.1794	10.5905	12.7699	3.1925	9.5774	2.6000	6.9774	19.1160	Overflow
1974	2.6000	0.7810	3.3810	0.8452	2.5357	2.5357	0.0000	0.0000	
1975	2.5357	7.5889	10.1246	2.5312	7.5935	2.6000	4.9935	13.6806	
1976	2.6000	5.3377	7.9377	1.9844	5.9533	2.6000	3.3533	9.1870	
1977	2.6000	5.5773	8.1773	2.0443	6.1330	2.6000	3.5330	9.6793	
1978	2.6000	6.3147	8.9147	2.2287	6.6860	2.6000	4.0860	11.1944	
1979	2.6000	5.5218	8.1218	2.0304	6.0913	2.6000	3.4913	9.5652	
1980	2.6000	6.6403	9.2403	2.3101	6.9302	2.6000	4.3302	11.8635	
1981	2.6000	6.4562	9.0562	2.2641	6.7922	2.6000	4.1922	11.4853	
1982	2.6000	0.9769	3.5769	0.8942	2.6827	2.6000	0.0827	0.0000	
1983	2.6000	8.6593	11.2593	2.8148	8.4445	2.6000	5.8445	16.0121	Overflow
1984	2.6000	5.6350	8.2350	2.0588	6.1763	2.6000	3.5763	9.7979	
1985	2.6000	6.9801	9.5801	2.3950	7.1851	2.6000	4.5851	12.5617	
1986	2.6000	2.7467	5.3467	1.3367	4.0100	2.6000	1.4100	3.8631	
1987	2.6000	0.0000	2.6000	0.6500	1.9500	2.6000	2.6000	7.1232	
1988	2.6000	5.3519	7.9519	1.9880	5.9639	2.6000	3.3639	9.2161	
1989	2.6000	9.3446	11.9446	2.9861	8.9584	2.6000	6.3584	17.4201	Overflow
1990	2.6000	5.2669	7.8669	1.9667	5.9002	2.6000	3.3002	9.0415	
1991	2.6000	4.3042	6.9042	1.7260	5.1781	2.6000	2.5781	7.0633	
1992	2.6000	6.6757	9.2757	2.3189	6.9568	2.6000	4.3568	11.9362	
1993	2.6000	4.5448	7.1448	1.7862	5.3586	2.6000	2.7586	7.5578	
1994	2.6000	7.0282	9.6282	2.4071	7.2212	2.6000	4.6212	12.6606	
1995	2.6000	2.5485	5.1485	1.2871	3.8614	2.6000	1.2614	3.4558	
1996	2.6000	8.5234	11.1234	2.7808	8.3425	2.6000	5.7425	15.7328	
1997	2.6000	6.6148	9.2148	2.3037	6.9111	2.6000	4.3111	11.8111	
1998	2.6000	4.2192	6.8192	1.7048	5.1144	2.6000	2.5144	6.8887	
1999	2.6000	0.0000	2.6000	0.6500	1.9500	1.9500	0.0000	0.0000	
2000	1.9500	0.0000	1.9500	0.4875	1.4625	1.4625	0.0000	0.0000	
2001	1.4625	1.7769	3.2394	0.8098	2.4295	2.4295	0.0000	0.0000	
2002	2.4295	0.0000	2.4295	0.6074	1.8222	1.8222	0.0000	0.0000	
2003	1.8222	3.3980	5.2202	1.3050	3.9151	2.6000	1.3151	3.6031	
2004	2.6000	0.0000	2.6000	0.6500	1.9500	1.9500	0.0000	0.0000	
2005	1.9500	12.9691	14.9191	3.7298	11.1893	2.6000	8.5893	23.5322	Overflow
2006	2.6000	5.6917	8.2917	2.0729	6.2188	2.6000	3.6188	9.9143	
2007	2.6000	0.4531	3.0531	0.7633	2.2898	2.2898	0.0000	0.0000	

Table 4.17 : Comparative Storages for Fateh Sagar Reservoir (in mcm)

Year	SOP storages	Storages at Max Release(opt)	Storages at Sustained Release(opt)	Actual Storages
1970	2.6051	2.6052	2.6052	2.6051
1971	2.6000	2.6000	7.6039	5.3590
1972	2.6000	3.1600	6.9329	3.2281
1973	2.1794	2.6000	3.9697	1.5008
1974	2.6000	2.6800	9.4573	6.4908
1975	2.5357	2.6000	6.2229	4.4995
1976	2.6000	2.6000	8.8972	6.7536
1977	2.6000	2.6000	9.2129	6.5140
1978	2.6000	2.6000	9.6296	5.7766
1979	2.6000	2.6000	10.5022	5.9465
1980	2.6000	2.6000	10.5567	5.4510
1981	2.6000	2.6000	11.4375	5.1537
1982	2.6000	2.6000	11.9581	6.1589
1983	2.6000	2.6000	8.2386	3.4320
1984	2.6000	2.6000	11.2490	6.4562
1985	2.6000	2.6000	11.1767	5.1112
1986	2.6000	2.6000	12.1625	6.2297
1987	2.6000	3.4667	9.7219	3.7378
1988	2.6000	2.6000	5.8314	0.4248
1989	2.6000	2.6000	6.9236	3.0299
1990	2.6000	2.6000	10.7427	6.8244
1991	2.6000	2.6000	10.5470	6.9659
1992	2.6000	2.6000	9.6803	5.4156
1993	2.6000	2.6000	10.8102	6.8385
1994	2.6000	2.6000	10.0576	5.0630
1995	2.6000	2.6000	11.3532	6.7960
1996	2.6000	2.6000	8.9649	5.2160
1997	2.6000	2.6000	11.6537	4.4741
1998	2.6000	2.6000	12.2403	4.7006
1999	2.6000	5.0647	10.8802	5.1395
2000	1.9500	3.7985	6.7002	3.2848
2001	1.4625	2.8489	3.5651	1.4088
2002	2.4295	3.4667	3.4667	1.3473
2003	1.8222	2.6000	2.6000	0.0000
2004	2.6000	3.4667	3.4667	1.3592
2005	1.9500	2.6000	2.6000	0.0000
2006	2.6000	2.6000	2.8667	6.3996
2007	2.6000	3.0133	4.9600	6.0032

fig. 4.8

Table 4.18 : Comparative Releases for Fateh Sagar Reservoir (in mcm)

Year	SOP Releases	Max Release(opt)	Sustained Release(opt)	Actual Releases
1970	6.4685	6.4639	1.4600	10.1630
1971	2.0419	1.4800	1.4600	9.5424
1972	0.0000	0.0000	1.4600	3.1032
1973	6.9774	7.2100	1.4600	7.0621
1974	0.0000	0.0000	1.4600	2.6145
1975	4.9935	5.0400	1.4600	6.3422
1976	3.3533	3.3500	1.4600	6.9985
1977	3.5330	3.5300	1.4600	9.0769
1978	4.0860	4.0900	1.4600	8.3787
1979	3.4913	3.4900	1.4600	8.6308
1980	4.3302	4.3300	1.4600	10.7255
1981	4.1922	4.1900	1.4600	6.9822
1982	0.0827	0.0800	1.4600	5.2599
1983	5.8445	5.8400	1.4600	7.1568
1984	3.5763	3.5800	1.4600	10.8419
1985	4.5851	4.5900	1.4600	7.7774
1986	1.4100	0.5433	1.4600	8.2041
1987	2.6000	0.0000	1.4600	0.0000
1988	3.3639	3.3600	1.4600	0.0776
1989	6.3584	6.3600	1.4600	6.1482
1990	3.3002	3.3000	1.4600	5.7603
1991	2.5781	2.5800	1.4600	8.3205
1992	4.3568	4.3600	1.4600	6.1095
1993	2.7586	2.7600	1.4600	9.5191
1994	4.6212	4.6200	1.4600	6.2258
1995	1.2614	1.2600	1.4600	4.9108
1996	5.7425	5.7400	1.4600	2.1141
1997	4.3111	4.3100	1.4600	9.9070
1998	2.5144	0.0453	1.4600	4.2475
1999	0.0000	0.0000	1.4600	0.7002
2000	0.0000	0.0000	1.4600	1.1734
2001	0.0000	0.0000	0.5372	2.8662
2002	0.0000	0.0000	0.0000	1.8968
2003	1.3151	1.0333	1.0330	3.2584
2004	0.0000	0.0000	0.0000	2.5892
2005	8.5893	9.0800	1.4600	9.1157
2006	3.6188	3.2067	1.4600	8.3981

fig. 4.9

Table 4.19 : Inflow v/s Maximum Release (Optimized) for Fateh Sagar Reservoir
(LDR Data in mcm)

Q _t	R _t
9.486134669	6.46386
3.589156923	1.48
0.283168199	0
10.59049065	7.21
0.780977893	0
7.591739417	5.04
5.337720553	3.35
5.605597669	3.53
6.22970038	4.09
5.521779882	3.49
6.640294268	4.33
6.456234939	4.19
0.976930287	0.08
8.659283528	5.84
5.635047162	3.58
6.980096107	4.59
2.746731531	0.5433
0	0
3.652869768	3.36
9.061382371	6.36
5.266928503	3.3
4.304156626	2.58
6.675690293	4.36
4.544849595	2.76
7.028234701	4.62
2.548513792	1.26
1.77829629	5.74
6.61480913	4.31
4.219206166	0.0453
0	0
0	0
1.782543813	0
0	0
3.398018389	1.0333
0	0
12.96910352	9.08
5.691680801	3.206667
0.453069119	0

Fig. 4.10

4.3.4. Reservoir Operation Policies for Pichhola Reservoir

The reservoir Pichhola is the only reservoir of upper Berach basin for which the LINDO package gives feasible solution at 25 percent(3.419 mcm) storage; therefore, SOP (Table 4.20) is prepared at this feasible conservation storage. The reservoir can safely accommodate 2.8 mcm water above its maximum gauge. The safe maximum storage was recorded in the year 2005 as 14.83 mcm. The comparison of minimum storages and releases obtained by SOP, Maximum release optimization and Maximum Sustained release optimization with actual storage and releases are shown in Tables 4.21.& 4.22, Fig. 4.11 & 4.12. In SOP the minimum storages can be maintained at 25 percent for 85 percent times, Therefore even SOP can be used to maintain the required levels.

The sustained release optimization keeps the reservoir between 25 percent to 55 percent with 35 percent storage(above sill level) for most of the times. The good levels in the reservoirs will augment the ground water storages continuously .The sustained release obtained from optimization for Pichhola reservoir is 2.19 mcm water i.e for 65 percent times, there will be ensured drinking water availability of 6 mld and atleast 4 mld for another 10 percent times. There will be atleast 15 percent years when no supply can be made, but the continuous recharging of ground water, because of maintained storage levels , will sustain and support the drinking water supply. The Linear Decision Rule is prepared using the inflow data and optimized maximum releases (Table 4.23 & Fig. 4.13). The linear regression analysis gives the value of R^2 as 0.8773. The LDR for Pichhola Reservoir is

$$R_t = 0.5216Q_t - 0.9857.(4.4)$$

This means that no release should be made if inflow is less then 1.8897 mcm (67 mcft)

Table 4.20 : Standard Operation Policy for Pichhola Reservoir (in mcm)

Year	S_{tmin}	Q_t	S_{t+Q_t}	L_t	Net Available	S_{t+1}	R_t	R_t in mld
1970	3.4190	11.4110	14.8300	5.9320	8.8980	3.4190	5.4790	15.0110
1971	3.4190	5.3160	8.7350	3.4940	5.2410	3.4190	1.8220	4.9918
1972	3.4190	0.1345	3.5535	1.4214	2.1321	2.1321	0.0000	0.0000
1973	3.4190	14.8300	18.2490	7.2996	10.9494	3.4190	7.5304	20.6312
1974	3.4190	1.2530	4.6720	1.8688	2.8032	2.8032	0.0000	0.0000
1975	3.4190	12.2012	15.6202	6.2481	9.3721	3.4190	5.9531	16.3099
1976	3.4190	5.2386	8.6576	3.4630	5.1946	3.4190	1.7756	4.8645
1977	3.4190	9.1147	12.5337	5.0135	7.5202	3.4190	4.1012	11.2362
1978	3.4190	10.7429	14.1619	5.6648	8.4971	3.4190	5.0781	13.9127
1979	3.4190	3.9077	7.3267	2.9307	4.3960	3.4190	0.9770	2.6768
1980	3.4190	11.5924	15.0114	6.0046	9.0068	3.4190	5.5878	15.3092
1981	3.4190	8.8150	12.2340	4.8936	7.3404	3.4190	3.9214	10.7436
1982	3.4190	2.7890	6.2080	2.4832	3.7248	3.4190	0.3058	0.8378
1983	3.4190	12.7109	16.1299	6.4520	9.6779	3.4190	6.2589	17.1478
1984	3.4190	9.0580	12.4770	4.9908	7.4862	3.4190	4.0672	11.1430
1985	3.4190	11.5220	14.9410	5.9764	8.9646	3.4190	5.5456	15.1934
1986	3.4190	3.6250	7.0440	2.8176	4.2264	3.4190	0.8074	2.2121
1987	3.4190	0.0056	3.4246	1.3698	2.0548	2.0548	0.0000	0.0000
1988	3.4190	9.9680	13.3870	5.3548	8.0322	3.4190	4.6132	12.6389
1989	3.4190	9.1463	12.5653	5.0261	7.5392	3.4190	4.1202	11.2882
1990	3.4190	10.3323	13.7513	5.5005	8.2508	3.4190	4.8318	13.2378
1991	3.4190	9.5960	13.0150	5.2060	7.8090	3.4190	4.3900	12.0274
1992	3.4190	12.6543	16.0733	6.4293	9.6440	3.4190	6.2250	17.0547
1993	3.4190	6.7779	10.1969	4.0788	6.1181	3.4190	2.6991	7.3949
1994	3.4190	12.7109	16.1299	6.4520	9.6779	3.4190	6.2589	17.1478
1995	3.4190	4.4599	7.8789	3.1516	4.7273	3.4190	1.3083	3.5845
1996	3.4190	13.7020	17.1210	6.8484	10.2726	3.4190	6.8536	18.7770
1997	3.4190	7.1190	10.5380	4.2152	6.3228	3.4190	2.9038	7.9556
1998	3.4190	5.4500	8.8690	3.5476	5.3214	3.4190	1.9024	5.2121
1999	3.4190	2.6050	6.0240	2.4096	3.6144	3.4190	0.1954	0.5353
2000	3.4190	2.0950	5.5140	2.2056	3.3084	3.3084	0.0000	0.0000
2001	3.4190	4.5590	7.9780	3.1912	4.7868	3.4190	1.3678	3.7474
2002	3.4190	5.8890	9.3080	3.7232	5.5848	3.4190	2.1658	5.9337
2003	3.4190	5.6630	9.0820	3.6328	5.4492	3.4190	2.0302	5.5622
2004	3.4190	0.3390	3.7580	1.5032	2.2548	2.2548	0.0000	0.0000
2005	3.4190	14.8300	18.2490	7.2996	10.9494	3.4190	7.5304	20.6312
2006	3.4190	8.9447	12.3637	4.9455	7.4182	3.4190	3.9992	10.9568
2007	3.4190	1.5260	4.9450	1.9780	2.9670	2.9670	0.0000	0.0000

Table 4.21 : Comparative Storages for Pichhola Reservoir (in mcm)

Year	SOP storages	Storages at Max Release (Optimized)	Storages at Sustained Release (Optimized)	Actual Storages
1970	3.4190	3.5390	3.5390	3.5396
1971	3.4190	3.9564	6.0134	6.7394
1972	3.4190	5.5638	5.5638	2.4494
1973	2.1321	3.4190	3.4190	1.5574
1974	3.4190	4.4483	7.1314	6.7394
1975	2.8032	3.4190	3.4190	4.2758
1976	3.4190	3.4190	5.5014	7.0226
1977	3.4190	3.4190	4.2508	7.3624
1978	3.4190	3.4190	4.1505	5.7342
1979	3.4190	3.4190	5.0703	6.2014
1980	3.4190	3.4190	3.4190	4.8847
1981	3.4190	3.4190	5.1414	4.3891
1982	3.4190	3.4190	6.1848	5.4227
1983	3.4190	3.4190	3.4190	3.7661
1984	3.4190	3.4190	5.8114	7.4190
1985	3.4190	3.4190	5.0468	4.9554
1986	3.4190	5.8638	6.0681	6.5129
1987	3.4190	5.6983	5.6983	4.5590
1988	2.0548	3.4190	3.4190	0.0142
1989	3.4190	3.4190	5.8414	4.5307
1990	3.4190	3.4190	6.8048	6.1447
1991	3.4190	3.4190	6.4129	6.8810
1992	3.4190	3.4190	5.7377	3.8228
1993	3.4190	3.4190	7.1627	6.4279
1994	3.4190	3.4190	6.1775	3.7661
1995	3.4190	3.4190	7.4665	7.1500
1996	3.4190	3.4190	4.9699	2.7750
1997	3.4190	3.4190	7.3319	5.5841
1998	3.4190	3.4190	6.4791	5.1678
1999	3.4190	3.4190	4.9675	4.6723
2000	3.4190	3.5983	3.5983	3.0299
2001	3.3084	3.4190	3.4190	1.3592
2002	3.4190	3.4190	3.4190	1.0477
2003	3.4190	3.4190	3.4190	1.3875
2004	3.4190	5.3650	5.3650	0.7929
2005	2.2548	3.4190	3.4190	0.0000
2006	3.4190	3.4190	8.7614	7.5323
2007	3.419	4.1650	6.7568	6.824

fig. 4.11

Table 4.22 : Comparative Releases for Pichhola Reservoir (in mcm)

Year	SOP Release	Maximum Release (Optimized)	Sustained Release (Optimized)	Actual Release
1970	4.7146	4.2470	2.1900	1.4668
1971	1.8220	0.0000	1.2340	4.7841
1972	0.0000	0.0000	0.0000	0.0000
1973	5.1320	4.8730	2.1900	1.4668
1974	0.0000	0.0000	1.6098	0.5196
1975	3.9036	4.2724	2.1900	1.1836
1976	1.7756	1.7724	2.1900	0.0000
1977	2.4212	2.4224	2.1900	2.4721
1978	3.3981	3.4024	2.1900	2.0048
1979	0.9770	0.9724	1.9631	1.1808
1980	3.9078	3.9124	2.1900	3.8171
1981	3.9214	3.9224	2.1900	2.4998
1982	0.3058	0.3024	1.9619	1.1610
1983	4.5789	4.5824	2.1900	0.7872
1984	2.3872	2.3824	2.1900	3.2508
1985	3.8656	1.4175	2.1900	1.6933
1986	0.8074	0.0000	0.1225	1.5234
1987	0.0000	0.0000	0.0000	2.7552
1988	3.7947	4.6124	2.1900	1.4583
1989	4.1202	4.1224	2.1900	2.0615
1990	3.1518	3.1524	2.1900	1.3252
1991	2.7100	2.7124	2.1900	4.3834
1992	4.5450	4.5424	2.1900	1.7783
1993	2.6991	2.7024	2.1900	4.1574
1994	4.5789	4.5824	2.1900	1.0562
1995	1.3083	1.3124	2.1900	4.1909
1996	5.1736	5.1724	2.1900	2.6221
1997	2.9038	2.9024	2.1900	2.4539
1998	1.9024	1.9024	2.1900	1.6990
1999	0.1954	0.0130	0.9422	1.3366
2000	0.0000	0.0000	0.0000	1.7160
2001	1.3014	1.3724	1.3724	2.5032
2002	2.1658	2.1624	2.1624	2.7750
2003	2.0302	0.0864	0.0864	3.4377
2004	0.0000	0.0000	0.0000	0.6796
2005	6.8319	7.5324	2.1900	1.3705
2006	2.3192	1.5764	2.1900	1.3822

fig. 4.12

Table 4.23 : Inflow v/s Maximum Release (Optimized) for Pichhola Reservoir
(LDR Data in mcm)

Q_t	R_t
10.1374	4.2470
5.3165	0.0000
0.1345	0.0000
12.1196	4.8730
1.2530	0.0000
9.4012	4.2724
5.2386	1.7724
6.3147	2.4224
7.9429	3.4024
3.9077	0.9724
8.7924	3.9124
8.8150	3.9224
2.7892	0.3024
9.9109	4.5824
6.2580	2.3824
8.7216	1.4175
3.6246	0.0000
0.0566	0.0000
9.9675	4.6124
9.1463	4.1224
7.5323	3.1524
6.7960	2.7124
9.8543	4.5424
6.7779	2.7024
9.9109	4.5824
4.4599	1.3124
10.9020	5.1724
7.1188	2.9024
5.4510	1.9024
2.6051	0.0130
2.0954	0.0000
4.5590	1.3724
5.8899	2.1624
5.6634	0.0864
0.3398	0.0000
14.8380	7.5324
6.1447	1.5764
1.5260	0.0000

Fig 4.13	
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4.3.5. Reservoir Operation Policies for Udai Sagar Reservoir

The reservoir Udai Sagar is the only reservoir of upper Berach basin for which the LINDO package does not give feasible solution at appreciable minimum storage levels. The software gives feasible solution at just 5.6 percent storage (1.77 mcm); therefore, SOP (Table 4.24) is prepared at this feasible conservation storage. The comparison of minimum storages and releases obtained by SOP, maximum release optimization and maximum sustained release optimization with actual storage and releases are shown in Table 4.25 & 4.26, Fig. 4.14 & 4.15.

The sustained release optimization keeps the reservoir storages between 5.6 percent to 60 percent with levels above sill level for just 30 percent times. This indicates that the reservoir needs some augmentation. However the maintained levels in the reservoirs will augment the ground water storages continuously. The sustained release obtained from optimization for Udai Sagar reservoir is 12 mcm water .The reservoir can release this much amount for 50 percent times and 10 mcm water for 8 percent times . The analysis shows that for all criteria applied, the reservoir performs very poor as far as minimum storages and releases are concerned. The Linear Decision Rule is prepared using the inflow data and optimized maximum releases (Table 4.27 & Fig. 4.16). The linear regression analysis gives the value of R^2 as 0.9944. The LDR for Udai Sagar Reservoir is

$$R_t = 0.8514Q_t - 0.587. \dots\dots\dots(4.5)$$

This means that no release should be made if inflow is less then 0.69 mcm(25 mcft)

Table 4.24 : Standard Operation Policy for Udai Sagar Reservoir (in mcm)

Year	S_t	Q_t	S_t+Q_t	L_t	Net available	S_{t+1}	R_t
1970	1.7727	20.3149	22.0876	4.6384	17.4492	1.7700	15.6792
1971	1.7700	0.5663	2.3363	0.4906	1.8457	1.7700	0.0757
1972	1.7700	1.3097	3.0797	0.6467	2.4329	1.7700	0.6629
1973	1.7700	29.5973	31.3673	6.5871	24.7802	1.7700	23.0102
1974	1.7700	0.5451	2.3151	0.4862	1.8289	1.7700	0.0589
1975	1.7700	26.1511	27.9211	5.8634	22.0577	1.7700	20.2877
1976	1.7700	23.2769	25.0469	5.2598	19.7870	1.7700	18.0170
1977	1.7700	18.2081	19.9781	4.1954	15.7827	1.7700	14.0127
1978	1.7700	27.4820	29.2520	6.1429	23.1091	1.7700	21.3391
1979	1.7700	1.8760	3.6460	0.7657	2.8804	1.7700	1.1104
1980	1.7700	1.8406	3.6106	0.7582	2.8524	1.7700	1.0824
1981	1.7700	4.4175	6.1875	1.2994	4.8881	1.7700	3.1181
1982	1.7700	0.5380	2.3080	0.4847	1.8233	1.7700	0.0533
1983	1.7700	29.8550	31.6250	6.6413	24.9838	1.7700	23.2138
1984	1.7700	10.6190	12.3890	2.6017	9.7873	1.7700	8.0173
1985	1.7700	10.6615	12.4315	2.6106	9.8209	1.7700	8.0509
1986	1.7700	0.4304	2.2004	0.4621	1.7383	1.7383	0.0000
1987	1.7383	0.9628	2.7011	0.5672	2.1339	1.7700	0.3639
1988	1.7700	1.8406	3.6106	0.7582	2.8524	1.7700	1.0824
1989	1.7700	17.2453	19.0153	3.9932	15.0221	1.7700	13.2521
1990	1.7700	25.9670	27.7370	5.8248	21.9123	1.7700	20.1423
1991	1.7700	4.3184	6.0884	1.2786	4.8098	1.7700	3.0398
1992	1.7700	28.6713	30.4413	6.3927	24.0487	1.7700	22.2787
1993	1.7700	3.6388	5.4088	1.1358	4.2729	1.7700	2.5029
1994	1.7700	28.4023	30.1723	6.3362	23.8361	1.7700	22.0661
1995	1.7700	0.4956	2.2656	0.4758	1.7898	1.7700	0.0198
1996	1.7700	4.3042	6.0742	1.2756	4.7987	1.7700	3.0287
1997	1.7700	2.9025	4.6725	0.9812	3.6913	1.7700	1.9213
1998	1.7700	2.0530	3.8230	0.8028	3.0202	1.7700	1.2502
1999	1.7700	0.0000	1.7700	0.3717	1.3983	1.3983	0.0000
2000	1.3983	0.4701	1.8684	0.3924	1.4760	1.4760	0.0000
2001	1.4760	2.1734	3.6494	0.7664	2.8830	1.7700	1.1130
2002	1.7700	0.0000	1.7700	0.3717	1.3983	1.3983	0.0000
2003	1.3983	0.1926	1.5909	0.3341	1.2568	1.2568	0.0000
2004	1.2568	0.3964	1.6532	0.3472	1.3060	1.3060	0.0000
2005	1.3060	24.7777	26.0838	5.4776	20.6062	1.3983	19.2079
2006	1.3983	29.3912	30.7895	6.4658	24.3237	1.7700	22.5537
2007	1.7700	0.0000	1.7700	0.3717	1.3983	1.3983	0.0000

Table 4.25 : Comparative Storages for Udai Sagar Reservoir (in mcm)

Year	SOP storages	Storages at Max Release(opt)	Storages at Sustained Release(opt)	Actual Storages
1970	1.7727	1.7700	1.7700	1.7727
1971	1.7700	1.7700	5.4483	5.9467
1972	1.7700	1.7700	1.7700	2.2442
1973	1.7700	1.7700	1.7700	1.5518
1974	1.7700	1.7700	12.7783	8.2333
1975	1.7700	1.7700	1.7700	3.5821
1976	1.7700	1.7700	10.0583	6.4564
1977	1.7700	1.7700	14.3361	6.7395
1978	1.7700	1.7700	13.7054	3.6671
1979	1.7700	1.7700	20.5373	7.5041
1980	1.7700	1.7700	5.7045	3.3273
1981	1.7700	1.7700	1.7700	2.5486
1982	1.7700	1.7700	1.7700	2.8317
1983	1.7700	1.7700	1.7700	1.2941
1984	1.7700	1.7700	12.9883	3.5397
1985	1.7700	1.7700	6.6508	2.9025
1986	1.7700	1.8101	1.8101	3.2225
1987	1.7383	1.7700	1.7700	1.2601
1988	1.7700	1.7700	1.7700	1.6990
1989	1.7700	1.7700	1.7700	1.1327
1990	1.7700	1.7700	3.0183	3.5680
1991	1.7700	1.7700	10.8944	4.1768
1992	1.7700	1.7700	1.7700	2.4778
1993	1.7700	1.7700	12.0483	4.8140
1994	1.7700	1.7700	1.7700	2.7468
1995	1.7700	1.7700	11.8380	5.9042
1996	1.7700	1.7700	1.7700	2.3787
1997	1.7700	1.7700	1.7700	0.4956
1998	1.7700	1.7700	1.7700	2.7893
1999	1.7700	2.2432	2.2432	2.4778
2000	1.3983	1.7722	1.7722	1.2176
2001	1.4760	1.7700	1.7700	1.1327
2002	1.7700	2.7208	2.7209	1.2941
2003	1.3983	2.1495	2.1494	1.1327
2004	1.2568	1.8481	1.8481	1.1327
2005	1.3060	1.7700	1.7700	0.0000
2006	1.3983	1.7700	1.7700	5.1679

fig. 4.14

Table 4.26 : Comparative Releases for Udai Sagar Reservoir (in mcm)

Year	SOP Release	Max Release(opt)	Sustained Release(opt)	Actual Release
1970	15.6792	15.6780	12.0000	11.5025
1971	0.0757	0.0783	2.9841	2.9011
1972	0.6629	0.6583	0.6583	1.2557
1973	23.0102	25.7083	12.0000	16.3745
1974	0.0589	0.0583	10.8878	3.3528
1975	20.2877	20.2883	12.0000	17.0329
1976	18.0170	18.0183	12.0000	16.7497
1977	14.0127	14.0083	12.0000	16.1534
1978	21.3391	24.0283	12.0000	17.1037
1979	1.1104	1.1083	12.0000	4.0830
1980	1.0824	1.0783	5.8653	1.7019
1981	3.1181	3.1183	3.1183	2.6715
1982	0.0533	0.0583	0.0058	1.3680
1983	23.2138	25.9083	12.0000	21.0681
1984	8.0173	8.0183	12.0000	8.2828
1985	8.0509	8.0082	12.0000	7.5154
1986	0.0000	0.0000	1.2188	1.6257
1987	0.3639	0.3883	0.3830	0.0571
1988	1.0824	1.0783	1.0783	1.6636
1989	13.2521	13.2483	12.0000	10.9506
1990	20.1423	20.1383	12.0000	19.1559
1991	3.0398	3.0383	10.2466	4.2334
1992	22.2787	24.9683	12.0000	20.9124
1993	2.5029	2.4983	12.0000	3.7072
1994	22.0661	24.7583	12.0000	18.7036
1995	0.0198	0.0183	10.5612	2.7442
1996	3.0287	3.0283	3.0283	4.7839
1997	1.9213	1.9183	1.9183	2.1323
1998	1.2502	0.7750	0.7750	1.3476
1999	0.0000	0.0000	0.0000	0.7398
2000	0.0000	0.0000	0.0000	0.2006
2001	1.1130	0.3974	0.3974	1.3177
2002	0.0000	0.0000	0.0000	0.0000
2003	0.0000	0.0000	0.0000	0.0000
2004	0.0000	0.0000	12.0000	1.2080
2005	19.2079	19.1983	12.0000	14.4065
2006	22.5537	25.5383	12.0000	23.8917

fig 4.15

Table 4.27 : Inflow v/s Maximum Release (Optimized) for Udai Sagar Reservoir (LDR Data)

Q_t	R_t
20.31488928	15.678
0.566347624	0.0783
1.309678881	0.6583
29.59732684	25.7083
0.545109588	0.0583
26.15110155	20.2883
23.27688735	18.01829
18.20807612	14.00833
27.48201846	24.02829
1.876026505	1.1083
1.840629779	1.0783
4.417511469	3.1183
0.538030243	0.0583
29.85501501	25.9083
10.61901795	8.0183
10.66149403	8.008173
0.430424194	0
0.962790961	0.3883
1.840629779	1.0783
17.24528516	13.2483
25.96703857	20.1383
4.318400634	3.0383
28.67134847	24.9683
3.638783485	2.4983
28.40233335	24.7583
0.495554171	0.0183
4.304241944	3.0283
2.902531574	1.9183
2.053010138	0.775
0	0
0.470068528	0
2.173359008	0.39742
0	0
0.192558192	0
0.396443337	0
24.77770856	19.19829
29.3912	25.5383

fig 4.16

4.3.6. Ensuring Drinking Water Supply to Udaipur

4.3.6.1. Sustained Release Criteria

The quantity of total ensured sustained drinking water availability from Fateh Sagar and Pichhola, as obtained from sustained release optimization is 10 mld. The present water availability from Mansi Wakal I, Jai Samand Scheme and ground water sources is 50 mld. Therefore, the total water availability of 60 mld would be more than sufficient to meet the present demand of 0.45 million local populations and floating tourist population. In the year 2011, the population of Udaipur is projected to be 0.5 million. By that time, Dewas II scheme will be functional and will provide 11 mld ensured supply. The total availability of 71 mld water will satisfactorily meet the demand of the year 2011.

The population of Udaipur as projected for the years 2021, 2031 and 2041 will be 0.6, 0.7 and 0.8 million respectively. To ensure water availability, and meet the demand of future years, Dewas III & IV schemes and Mansi Wakal II scheme should be implemented. The water available from these schemes will be of the order of 110 mld which will not only meet the drinking water demands of local residents and tourist floating population, but shall also make the upper Berach basin, Udaipur a water-surplus area.

4.3.6.2. Maximum (Optimized) Release Criteria

The maximum release criterion is based on the availability of water in the reservoirs through inflows. The quantity of water available from Fateh Sagar & Pichhola reservoirs is in the range of 6 mld to 45 mld. This means that during good rainfall years, a significant quantity of water can be withdrawn from these reservoirs. The additional water available from the existing, under-construction, and proposed inter basin transfer schemes will not only keep the reservoirs at excellent levels and facilitate recharging of ground water, but will also convert this area from water-deficit to water-surplus.

4.3.7. Ensuring Irrigation and Industrial Water Supplies

4.3.7.1 Sustained Release Criteria

The ensured water availability from Madar, Badi & Udai Sagar reservoirs, as obtained from this study is 12.78 mcm, which can meet the irrigation demand of 2000 hectare area (delta 0.6 m). It is to be noted that the maximum irrigation done so far, from these reservoirs, is for 3000 ha. Further, the continuous recharging of down stream wells and tube wells will supplement the irrigation water demands.

4.3.7.2 Maximum Release Criteria

The maximum release criterion is based on the availability of water in the reservoirs through inflows. The quantity of water available from these reservoirs can go up to 31 mcm. This means that irrigation can be extended to 5000 ha. and the industrial needs can be satisfactorily fulfilled.

Further to utilize the available water optimally, the surface and ground water should be used conjunctively and less water requiring crops should be sown in this basin.

4.3.8. Reversal of Eutrophication

Complete and total reuse of waste water, organic farming in the catchment areas, establishment of sewerage treatment plants, bio control of aquatic weeds, phyto remediation of Ahar river, aeration of surface waters, rejuvenation of native fish species, protection of migratory bird species are some of the measures which should be implemented for reversal of eutrophication of the aforesaid reservoirs.

4.3.9. General Recommendations

Though this study pertains to draw eco-technological operation and management plan for selected surface water reservoirs of upper Berach basin, Udaipur, the findings and recommendations are applicable and useful for all surface water reservoirs of the country. The recommendations owe their origin to principles laid down in World Lake Vision. These principles are :

- Principle 1 : A harmonious relationship between humans and nature is essential for the sustainable use of lakes.
- Principle 2: A lake drainage basin is the logical starting point for planning and management actions for sustainable lake use.
- Principle 3 : A long-term, preventative approach directed to preventing the causes of lake degradation is essential.
- Principle 4 : Policy development and decision making for lake management should be based on sound science and the best available information.
- Principle 5: The management of lakes for their sustainable use requires the resolution of conflicts among competing users of lake

resources, taking into account the needs of present and future generations and of nature.

- Principle 6 : Citizens and other stakeholders should be encourage to participate meaningfully in identifying and resolving critical lake problems.
- Principle 7 : Good governance, based on fairness, transparency and empowerment of all stakeholders, is essential for sustainable lake use.

Based on aforesaid principles, this study recommends following majors for ecotechnological management and operation of reservoirs:-

- (i) Accurate water budgets should be developed for individual reservoirs and their drainage basins- Developing an accurate water budget is a major step to managing water withdrawals from reservoirs and their tributaries, identifying both the available water resources, and the various demands for it in meeting water needs throughout the drainage basin. It must include the quantity of water needed to preserve life-supporting, economically and ecologically important ecosystem functions.
- (ii) Operation Policies based on mathematical optimization should be developed – Such operation policies should take in account the minimum conservation level required to sustain the ecosystem functions. Ecological water needs of reservoirs should be given equally important priority in all water allocation plans. The social and economic of water in making water management and allocation decisions should be recognized.
- (iii) Technical water conservation measures should be implemented to reduce water use – Water diversions from reservoirs and their tributaries are a direct result of growing water needs for irrigation, industrial and municipal use. Only by reducing the quantities of water used by these three major sectors, we can preserve adequate supplies of water for meeting beneficial human water uses and maintaining reservoir ecosystems. The vast majority of water on a global scale is used for agricultural irrigation. Further, much of the water used for crops and plants is evaporated directly back into the atmosphere, thereby not being returned to the water systems form which it was taken, reducing the potential for immediate downstream water reuse. The

largest potential water savings, therefore, can be obtained by implementing more efficient irrigation techniques (e.g., drip irrigation, micro-irrigation systems), changing cropping practices or products. Substantial water savings also are possible by implementing more efficient industrial and domestic water-use, upgrading urban water delivery systems that lose large amounts of water through leakage, and using low-flow or dry toilets in individual households. Additional water savings can be realized with the implementation of other innovative water conservation approaches, including reuse of gray water and of treated water from municipal wastewater treatment plants, rainwater harvesting, etc.

- (iv) Wastewater treatment plants within reservoir drainage basins should be constructed – The construction of adequate wastewater treatment facilities is a one of the top priority. Experience around the world suggests that large wastewater treatment systems generally are the most effective approach in urban areas with large populations and water usage. In addition to improving local hygienic conditions, upgrading existing wastewater systems to remove the largest quantities of biologically available phosphorus and other pollutants in wastewater is also an important measure. In sparsely-populated villages of the catchment areas, small community based projects for meeting local sanitation needs, including the use of constructed wetlands are effective, less expensive and more practical than large infrastructure projects. Ecological sanitation that separately recovers urine and feces for fertilizers also may be a promising approach for reducing water pollution.
- (v) The use of phosphate-based detergents should be banned – Because phosphorus in detergents typically is in a chemical form that algae and other aquatic plants can readily use, thereby promoting reservoir eutrophication, the phosphorus content of industrial and residential detergents is regulated in many industrialized countries. Many reservoirs in developing countries, however, still received substantial phosphorus loads from detergents. Manufacturers in many parts of the world have successfully replaced phosphorus with less environmentally-harmful ingredients, and many successful models for implementing phosphate detergent bans or limits are available.
- (vi) The forests and vegetation in the drainage basins should be protected and best management practices should be adopted to control soil erosion.

- (vii) The land use plans which limit the generation and transport of water pollutants should be developed and implemented.
- (viii) Management programmes should be implemented for sustainable fisheries. The introduction of invasive species should be prevented and controlled.
- (ix) Eco-technologies like aeration, bio control of aquatic weeds and bio manipulation should be used – It has been found that certain fish species like grass carp effectively control aquatic weeds. The weevils namely *N. eichhorniae*, *N. bruchi* totally eradicate the water hyacinth in less than a year. Aeration alone can reduce the ill effects of organic pollution by 50 percent.
- (x) Effective institutional mechanism for sustainable reservoir use should be developed – The statutory reservoir operation and management authorities should be established which should have proper participation of all stakeholders. Such authorities should work on the principles of Integrated Water Resources Management.

5. SUMMARY & CONCLUSIONS

5.1. Summary

The world famous interconnected surface water reservoirs of upper Berach Basin are facing serious environmental threats like degradation of catchment areas; blockages and encroachments in inlet and outlet channels; disturbances in rainfall pattern, intensity and duration ; sedimentation; waste water inflow; over exploration of water etc. The ultimate effects are frequent drying of these reservoirs and severe contamination of waters.

To maintain and conserve these reservoirs, eco-technological management-cum-operation is the first and foremost requirement as no operation policies have been drawn by any agency so far for these reservoirs.

Ecotechnological management and operation involve several structural measures. Demarcation and restoration of catchment areas and high flood levels of reservoirs, strengthening of embankments grouting of bed tubewells, laying of sewerage system and sewerage and construction of sewerage treatment plants are the main structural measures, some of which are either implemented or in the pipe line in the case of Udaipur reservoirs.

The non structural measures are basically hydrological, ecological and limnological management tools. The bio control of aquatic weeds, aeration of water, rejuvenation of native fish species, maintenance of conservation pool level and most importantly, the scientific allocation optimum of water from these reservoirs, considering ecological needs of local aquatic and terrestrial ecosystem are the main nonstructural measures which can sustain and conserve reservoir ecosystems and also the associated social and economic benefit, for years to come at minimal cost and labour.

To derive eco-technological operation and management plans of reservoirs of upper Berach basin, Udaipur, past 38 years data of rainfall, initial storages evaporation domestic, irrigation, industrial water withdrawals, pollution, augmentation etc. were collected and processed. The rainfall data of five stations were used to derive average rainfall and determine drought years. The morphometric details, along with aforesaid data, were used to derive linear decision rules, using linear programming.

The LINDO 6.2 release software was used to determine the feasible maximum conservation pool level for each reservoir . Using these pool levels, standard operation policy, sustained release policies and maximum (optimized) release policies were drawn for each reservoir. The results obtained from sustained release and maximum release criteria are quite

useful in protection, conservation and eco-technological management of world famous lakes of Udaipur.

The operation policies and decision rules, if implemented, will not only keep the reservoirs at certain appreciable levels but will also satisfactorily meet all demands associated with these reservoirs.

5.2. Conclusions

The study consisted of determining the eco-technological operation and management plans and allocation decision rules for the selected surface reservoirs of upper Berach basin, Udaipur. After completion of the present study, following operation policies have been drawn:-

(i) Reservoir Operation Policy for Bada Madar Reservoir

- (a) The feasible conservation pool level obtained is 0.38 mcm i.e. 16 percent of the total storage of this reservoir. At this conservation level, 2.76 m of water depth will be maintained, even in the critical dry periods.
- (b) At a sustained release of 0.3 mcm, the reservoir levels and water spread area will fluctuate between 16 percent to 38 percent, with 20 percent storage at most of the times. The linear Decision Rule (LDR) for maximum (Optimized) release is $R_t = 0.3274 Q_t - 0.2233$, with value of coefficient of regression R^2 as 0.7769. This means that no supply should be given if inflow to the reservoir is less than 0.68 mcm (24 mcft) .

(ii) Reservoir Operation Policy for Badi Reservoir

- (a) The feasible conservation pool level obtained is 2.4 mcm i.e. 23 percent of the total storage of this reservoir. At this conservation level, 12.8 m of water depth will be maintained, even in critical dry periods.
- (b) At a sustained release of 2 mcm, the reservoir levels and water spread area will fluctuate between 23 percent to 100 percent. The linear Decision Rule (LDR) for maximum (Optimized) release is $R_t = 0.8384 Q_t - 0.3929$, with value of coefficient of regression R^2 as 0.9976. This means that no supply should be given if inflow to the reservoir is less than 0.47 mcm (16.5 mcft). The average annual inflow to the reservoir is 2.65 mcm.

(iii) Reservoir Operation Policy for Fateh Sagar Reservoir

- (a) The feasible conservation pool level obtained is 2.6 mcm i.e. 21.5 percent of the total storage of this reservoir. At this conservation level, 4.35 m of water depth will be maintained, even in critical dry periods.
- (b) At a sustained release of 1.46 mcm (4 mld drinking water supply), the reservoir levels and water spread area will fluctuate between 21.5 percent to 100 percent with 60 percent storage for most of the times. The Linear Decision Rule (LDR) for maximum (Optimized) release is $R_t = 0.682 Q_t - 0.2192$, with value of coefficient of regression R^2 as 0.8413. This means that no supply should be given if inflow to the reservoir is less than 0.32 mcm (11.4 mcft). The average annual inflow to the reservoir is 4.55 mcm.
- (c) Since the reservoir can accommodate 1.58 mcm additional water during overflow years, this amount of water should be stored during overflow years.

(iv) Reservoir Operation Policy for Pichhola Reservoir

- (a) The feasible conservation pool level obtained is 3.419 mcm i.e. 25 percent of the total storage of this reservoir. At this conservation level, 2.5 m of water depth will be maintained, even in critical dry periods.
- (b) At a sustained release of 2.19 mcm (6 mld drinking water supply), the reservoir levels and water spread area will fluctuate between 25 percent to 55 percent with above sill water levels for most of the times.
- (c) The Linear Decision Rule (LDR) for maximum (Optimized) release is $R_t = 0.521 Q_t - 0.9887$, with value of coefficient of regression R^2 as 0.877. This means that no supply should be given if inflow to the reservoir is less than 1.89 mcm (67 mcft). The average annual inflow to the reservoir is 6.3 mcm.
- (d) Since the reservoir can accommodate 4 mcm additional water during overflow years, this amount of water should be stored during overflow years.

(v) Reservoir Operation Policy for Udai Sagar Reservoir

- (a) This is the only reservoir in the upper Berach basin for which LINDO Software does not give feasible solution above 10 percent storage. The feasible conservation pool level obtained is 1.77 mcm i.e. 5.7 percent of the total storage of this reservoir. At this conservation level, 3.6 m of water depth will be maintained, even in critical dry periods.
- (b) (b) At a sustained release of 12 mcm the reservoir levels and water spread area will fluctuate between 5.7 percent to 60 percent.
- (c) The Linear Decision Rule (LDR) for maximum (Optimized) release is $R_t = 0.8514 Q_t - 0.587$, with value of coefficient of regression R^2 as 0.9944. This means that no supply should be given if inflow to the reservoir is less than 0.69 mcm (25 mcft). The average annual inflow to the reservoir is 10.42 mcm.
- (d) This reservoir performs very poorly as far as minimum storage – a conservation pool level criterion is concerned. Therefore, the fraction of waste water (generated from upstream Udaipur city and villages) which is of the order of 40 mld (14 mcm annually) should be used for augmentation of Udai Sagar reservoir, after proper treatment.

Table 4.1 : Analysis of Rain fall, Drought and Reservoir overflow for Upper Berach Basin

S.N	Year	Average	Draught Classification			Overflow of Reservoirs of upper Berach Basin				
			Subrahmanim Classification	Walker Classification	IMD Classification	Madar Bada	Badi	Pichhola	Fateh Sagar	Udai Sagar
1	1970	798.4000				Overflowed		Overflowed	Overflowed	
2	1971	453.2333	Large	Normal	Slight	Overflowed				
3	1972	352.5667	Severe	Large	Moderate					
4	1973	1272.1667				Overflowed	Overflowed	Overflowed	Overflowed	overflowed
5	1974	440.2333	Large	Normal	Moderate					
6	1975	734.0667						Overflowed	Overflowed	
7	1976	633.2000				Overflowed			Overflowed	
8	1977	510.3333	Moderate	Normal	Slight	Overflowed		Overflowed	Overflowed	
9	1978	772.6000				Overflowed		Overflowed	Overflowed	overflowed
10	1979	544.2667	Moderate	Normal	Normal	Overflowed				
11	1980	597.3333	Moderate	Normal	Normal			Overflowed	Overflowed	
12	1981	676.4000				Overflowed				
13	1982	585.2333	Moderate	Normal	Normal					
14	1983	797.5667				Overflowed		Overflowed	Overflowed	overflowed
15	1984	610.6667				Overflowed		Overflowed	Overflowed	
16	1985	693.7000				Overflowed		Overflowed		
17	1986	365.9667	Severe	Large	Moderate					
18	1987	286.2000	Severe	Serious	Severe					
19	1988	552.8000	Moderate	Normal	Normal	Overflowed				
20	1989	697.6000				Overflowed			Overflowed	
21	1990	775.4667				Overflowed	Overflowed	Overflowed	Overflowed	
22	1991	501.6333	Large	Normal	Slight			Overflowed		
23	1992	777.9333						Overflowed		overflowed
24	1993	415.3667	Large	Large	Moderate	Overflowed				
25	1994	719.2250				Overflowed	Overflowed	Overflowed	Overflowed	overflowed
26	1995	374.9250	Severe	Large	Moderate					
27	1996	658.6000				Overflowed		Overflowed		
28	1997	592.4000	Moderate	Normal	Normal	Overflowed				
29	1998	583.5500	Moderate	Normal	Normal					
30	1999	389.9750	Severe	Large	Moderate					
31	2000	416.1750	Large	Large	Moderate					
32	2001	582.4500	Moderate	Normal	Normal					
33	2002	362.8833	Severe	Large	Moderate					
34	2003	559.4000	Moderate	Normal	Normal					
35	2004	542.3333	Moderate	Normal	Normal					
36	2005	810.0333				Overflowed		Overflowed	Overflowed	
37	2006	917.5500				Overflowed	Overflowed	Overflowed	Overflowed	overflowed

38	2007	471.0500	Large	Normal	Slight				
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Annexure A3 : Reservoir Evaporation and Seepage in Upper Berach Basin

S.No.	Year	Pan Evaporation	Reservoir Evaporation	Reservoir Seepage	Total losses in meters
1	1973	2.3420	1.6394	0.5110	2.1504
2	1974	2.3450	1.6415	0.5110	2.1525
3	1975	2.2020	1.5414	0.5110	2.0524
4	1976	1.9820	1.3874	0.5110	1.8984
5	1977	1.9130	1.3391	0.5110	1.8501
6	1978	1.9820	1.3874	0.5110	1.8984
7	1979	1.9530	1.3671	0.5110	1.8781
8	1980	2.0140	1.4098	0.5110	1.9208
9	1981	2.0070	1.4049	0.5110	1.9159
10	1982	1.8570	1.2999	0.5110	1.8109
11	1983	1.9325	1.3528	0.5110	1.8638
12	1984	1.9962	1.3973	0.5110	1.9083
13	1985	2.1157	1.4810	0.5110	1.9920
14	1986	2.2726	1.5908	0.5110	2.1018
15	1987	2.4888	1.7422	0.5110	2.2532
16	1988	2.2200	1.5540	0.5110	2.0650
17	1989	2.1186	1.4830	0.5110	1.9940
18	1990	1.8130	1.2691	0.5110	1.7801
19	1991	1.9392	1.3574	0.5110	1.8684
20	1992	1.9944	1.3961	0.5110	1.9071
21	1993	2.0737	1.4516	0.5110	1.9626
22	1994	1.9243	1.3470	0.5110	1.8580
23	1995	2.0623	1.4436	0.5110	1.9546
24	1996	2.0380	1.4266	0.5110	1.9376
25	1997	1.7915	1.2541	0.5110	1.7651
26	1998	1.7812	1.2468	0.5110	1.7578
27	1999	1.9460	1.3622	0.5110	1.8732
28	2000	2.1637	1.5146	0.5110	2.0256
29	2001	1.9774	1.3842	0.5110	1.8952
30	2002	2.0971	1.4680	0.5110	1.9790
31	2003	2.0310	1.4217	0.5110	1.9327
32	2004	2.0575	1.4403	0.5110	1.9513
33	2005	1.9493	1.3645	0.5110	1.8755